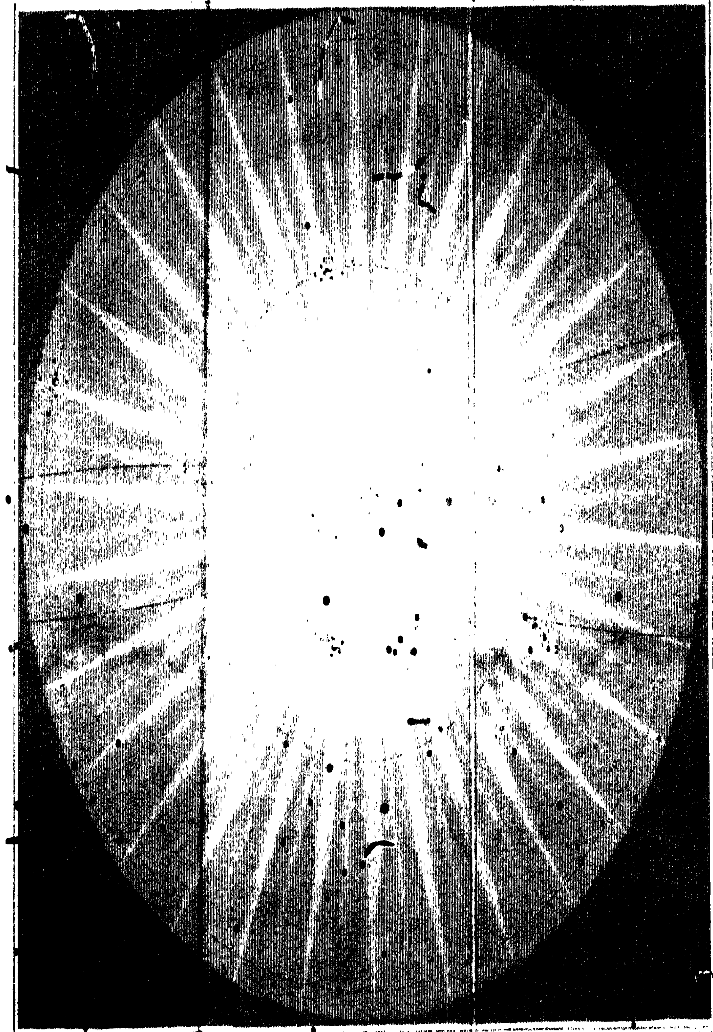
ASTRONOMY.

To face the Title — Plate I



Cooper Sculpt

London Published ... Jan 1, 1810

LETTERS

ON

NATURAL AND EXPERIMENTAL PHILOSOPHY,

ADDRESSED TO A YOUTH SETTLING IN THE METROPOLIS.

Illustrated with Seventeen Plates.

BY THE REV. J. JOYCE.

Author of "Scientific Dialogues,"

&c. &c.

SECOND EDITION,

WITH CONSIDERABLE ADDITIONS AND ALTERATIONS.

LONDON:

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PATERNOSTER-ROW;

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1821.

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TO THE

REV. A. REES, D. D. F. R. S.

EDITOR OF THE NEW CYCLOPÆDIA.

DEAR SIR,

As a public testimony of the esteem and respect which I feel for your character and talents; and of gratitude for the many friendly offices which I have experienced at your hands, I take the liberty of inscribing this Volume to you. With the various subjects discussed in it, in their mutual connection and dependence, you have been long intimately acquainted: of most of them you were many years a public instructor, and no small number of persons of the present age, who are occupying useful and highly important stations in society, as well as myself, are much indebted to your assiduous attentions for the knowledge which they possess in Mathematics, Natural Philosophy, and other branches of Science.

If the execution of this Work should merit your approbation, and be regarded by you, as tolerably well adapted to instruct young persons in the elements of knowledge, and calculated to excite in them an ardour for extending their enquiries into the laws and economy of nature, I shall feel happy in the conviction that I have not laboured in vain.

Hoping, Sir, that your life, devoted to the diffusion and extension of general Science, in all its branches, and in its higher departments, may be long spared, for the benefit of your country, and of mankind in general, and that for its latter years there may yet be stores of much happiness in reserve,

I am, Dear Sir,

Your sincere and obliged friend and servant,

JEREMIAH JOYCE.

Highgate, May 14, 1810.

ADVERTISEMENT

TO THE FIRST EDITION.

The object of this volume of letters is distinctly set forth in the introduction, which, with the annexed table of contents, will afford the reader an idea of the nature of the instruction which he may expect to derive from it.

When the subject was proposed to the author, he hesitated on the propriety of the undertaking, because he had already gone over much of the ground in the "Scientific Dialogues:" and in the "Dialogues on Chemistry;" and because he was aware that to bring into the plan all that was asked, would require more space than it was intended that the several parts should occupy. When, however, to the request of his friend, was added the desire of the late excellent Mr. Johnson, the publisher of his former volumes, his own difficulties, in a good measure, vanished, and he immediately set about preparing the letters for the press. They now solicit, as they will need, the candour of the public. The author would indeed feel a high degree of satisfaction if he could anticipate for this volume a reception, similar to that which the works already referred to, have experienced, and for which he can never reflect but with sentiments of gratitude.

It must not be forgotten, by those who read these

letters, or who recommend them to the perusal of others, that they are intended as an introduction for young people who have had no opportunity of studying the subjects before. They contain the elements of Experimental and Natural Philosophy, illustrated by a very considerable number of well engraved plates, and by experiments, selected from all sources of authority. They may be read in connection with any other works on the same subjects, and will, the author trusts, be particularly useful to those who attend the lectures of any of our public institutions.

The questions upon each letter at the end of the volume will afford ample matter for the examination of pupils in classes at school, and they are so drawn up as to be of essential service to others who have the advantage of no living instructor.—Let a person first read a letter, and then, referring back to the contents prefixed to it, ascertain whether he recollects the subjects discussed in their order and arrangement. Let him then examine his progress by means of the questions, and if, from these, without any other aid, he were to draw up a Letter or Essay on the same topics, he would infallibly derive from the exercise accurate ideas on the several sciences treated of, and a facility at composition that would be extremely useful to him on other occasions.

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ADVERTISEMENT

TO THE PRESENT EDITION.

A LARGE Edition of the following treatise having been disposed of, and the work still much sought after, the Proprietors are induced to offer a Second Edition, with corrections and considerable improvements.

The original Plan has been strictly adhered to, as not susceptible of any material Improvement.

The mechanism of clocks and watches, and the description of the steam-engine, has been rendered more complete in this than in the former Edition. The method of calculating the power of the latter machine is fully explained, and the theory of the tides is given in a way more satisfactory, and more conformable to the method adopted by its great discoverer.

Amongst other important new matter will be found an Explanation of the principles of the Achromatic telescope; of what is meant by double refraction and the polarisation of light, and an account of the curious magnetical experiments of Professor Oersted.

The Letters on chemistry, anatomy, physiology, and botany, have been purposely omitted as not properly belonging to a treatise of this kind; and because it would have been impossible to have done justice to these subjects without swelling the book to an inconvenient size.

S. L.

London, 1st August, 1821.

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LETTERS ON NATURAL PHILOSOPHY.

LETTER I.

Introduction, cause and object of the work explained, and the plan laid down.

My young Friend,

IN conformity with the request of your excellent father, made, I believe, with your consent and approbation, I now undertake to lay before you, in a series of letters, such a familiar account of the principles of natural philosophy, as shall enable you to pursue the subject yourself at your leisure, and, at the same time, prepare you for an attendance upon the lectures delivered at the Royal, or any other of our scientific institutions, to which your situation may give you a ready access.

The attention and kindness which you have ever experienced from him who sustains, with regard to you, the interesting character of a tender parent and affectionate friend, will, I am sure, induce you to pay a marked regard to whatever he recommends as likely to be useful in your future pursuits in life. With this persuasion I will, without hesitation, transcribe a part

of his letter, written on the subject, though not intended for your eye. The following is an extract:—

"Since my son left school I put into his hand the 'Scientific Dialogues,' with which he appears to be much interested, and by means of the questions contained in the supplementary volume, I have examined, as far as my leisure from business has allowed me, the progress that he has made in scientific knowledge; the result has been satisfactory to my mind. He is now leaving home for the metropolis, the thought of which creates in my heart a degree of anxiety that I never before experienced, and which, probably, none but a father, acquainted with the seductions of the world, can feel. Nothing, I apprehend, is so likely to secure the integrity and virtue of a youth entering the world, as to afford him full employment for his mind, and, if possible, to interest him in philosophical pursuits and scientific research. I know you will enter into my feelings, and I depend on you for seconding my views.

"What I particularly wish, is that you would, by a series of letters to my much loved son, become his instructor in important knowledge. Let him have from your pen discussions on the same subjects treated of in the volumes to which I have already referred. Divested of the form of dialogues, they will have the advantage of a certain degree of novelty, while, at the same time, they will necessarily bring to his recollection all the leading facts contained in the 'Scientific Dialogues.'

"He has, as you know, lately emerged from a

school, in which scarcely any thing was regarded as important but classical learning: he will now, probably, feel himself surrounded with objects that attract his attention and excite his curiosity: I am anxious that he should have that curiosity gratified by an explanation of the principles on which they act. I am desirous that he should comprehend the mechanism of clocks and watches, and of other things in familiar use, as well as of instruments more strictly denominated philosophical."

Such, my dear sir, are the anxious views of him, who is, and who justly claims to be, an object dearer to you than any other object in the world; and in compliance with the wish of my friend, and your father, I shall proceed to the task imposed on me. How far I shall be able to answer his expectations, or yours, I cannot pretend to judge. One thing, I hope, I may promise; my letters shall not indulge in any visionary theories, I will, in general, confine myself to principles that are either demonstrable in themselves, or which, having stood the test of examination, are admitted as true. You shall not, in your subsequent enquiries, have to unlearn, as erroneous, what my letters have represented as matters of fact. You may, and I trust you will, carry your researches much farther than I shall pretend to conduct you in the journey of science, and I shall be quite satisfied if my letters have the effect of exciting in you a thirst for philosophical knowledge.

I am fully aware of the difficulties and disadvantages under which a person must labour who attends public lectures on any science, without having first studied the

principles, in some work professedly introductory to the subjects discussed in the lecture room. These difficulties I shall, I trust, be able, in a great measure, to obviate with respect to yourself, if you consent to attend with some assiduity to each of my letters, which I will confine within as narrow limits as is consistent with perspicuity, and which you should not only read, but render familiar to your mind.

Conversation on these topics you would undoubtedly find of great advantage, but as our situations do not admit of this, I will at the end of each letter* give you a few leading questions, by means of which you may examine yourself as to what you have really learned from the perusal. If, upon such self-scrutiny, you find yourself incompetent to the task of answering every question proposed, you may be sure either that you have not read with sufficient attention, or that I have not illustrated the subject so well as I ought. In such circumstances let me recommend you to give the letter another perusal, which, I fear not, will, in almost all cases, solve your doubts, but if not, you must allow me the opportunity of a further explanation.

* These questions are thrown to the end of the volume, and they are so formed as to enable the student, not only to examine himself on the facts contained in each letter, but to furnish him with a sufficient clue to write, in his own words, on the same subject.

MECHANICS.

LETTER II.

Introduction to Mechanics—Matter defined, and its Properties investigated—Curious instances of the Divisibility of Matter Motion explained by familiar Examples — Composition of Forces.

HAVING explained to you my plan, and laid before you the topics which I mean particularly to engage your attention, I shall, my friend, without farther preface, begin with the subject of mechanics. This science, which is intimately connected with the arts of life, leads us to enquire into the forces by which bodies, whether animate or inanimate, may be made to act upon one another, and likewise into the means by which these may be increased, so as to overcome such as are more powerful. As introductory to " mechanics," you must be informed of the nature and properties of matter.

Every thing we see and feel may be called matter, which, in a philosophical sense, is defined a *solid, extended, inactive,* and *moveable* substance. This definition you will easily understand as applicable to any thing that you select as an example. The letter which you read, a book, the table, &c. are all composed of matter, for all are solid, have extension, are in themselves inactive, but may be moved. Cast your eyes

around you, and you will perceive nothing, however small, or however large, to which these properties do not apply. The earth on which you tread, and the air which you breathe, possess all these properties: the former may be too large for human force to move; but I shall prove to you that it has two motions, the one by which it is perpetually turning on its axis, and the other by which it travels 66,000 miles an hour in its journey round the sun: the latter, that is the air, you will soon perceive is as much a solid substance as the table at which you sit.

EXPERIMENT I. Take a glass tumbler, and invert it perfectly upright in a vessel of water; the water will rise only to a small height in the glass, because, though the air contained in it may be compressed, that is, may be made to occupy a smaller space than it naturally occupies, it is a solid substance, and will not admit another body in the part of space which it fills.

EX. II. Tie up a small quantity of air in a bladder, and you will have as much resistance from that as you would from a brick or a block of stone; and while the air remains in the bladder, it is as impossible to bring the sides together as it would the opposite sides of a brick.

What I have said of air you will readily believe is applicable to water, or to wine, or quicksilver, which are fluids as well as the air; the latter, indeed, is invisible, but our feelings assure us of its existence, as much as our sight does of that of other fluids. Therefore, by matter, I mean every thing in nature, whether solid or fluid.

It is difficult to say of what matter is composed; because, though it may be demonstrated to be capable of division without end, yet the smallest portion, after such division, is precisely of the same nature as the largest. Here, as far as mechanical instruments are concerned, we are stopped in our inquiries; by chemical analysis we can go farther, but still we are, probably, very far from finding out the nature of the first particles of matter from whence bodies originate.

You may, perhaps, be curious to know how it is proved that matter may be infinitely divided. That the thing is capable of demonstration you will easily comprehend: Suppose Plate I. fig. 1, *a b* to be a small particle of matter, and *a* to be the upper and *b* the under surface. I draw two parallel lines A B and C D, that is, lines which will never meet or come nearer together, though extended for ever; in the line A B I take any point, as *x*, and from that point I draw the lines *x v*; *x y*; *x z*; *x d*, &c. You perceive *x v* takes off a certain portion of the particle *ab*; *x y* takes off a larger part; and the other lines *x z*, *x d*, &c. other and larger portions; but if the two lines A B and C D were extended for ever, and lines drawn from *x* to the most remote part of C D, still the last line, if there could be a last line, would leave a portion of *a b* untouched, because the line *x d* could not coincide with A B.

It is true we have no instruments fine enough to carry on this sort of division to any very great length, but the thing is not less true because we are incapable of performing it, and I can repeat to you some very striking

instances in which the actual division of matter is carried to great lengths.

I. Silver and gold, melted together, easily incorporate, so that if a single grain of gold be melted with an ounce, or 5760 grains of silver, the gold will be equally diffused over the whole mass: if one grain of this mass be dissolved in nitric acid, the silver will unite with the acid, and the gold, which can be only the $\frac{1}{5761}$ part of a grain, will be found at the bottom of the vessel.

II. A single pound of wool has been spun into a thread of 168,000 yards long; a pound, avoirdupois, consists of 7,000 grains, therefore a yard of this thread will weigh only $\frac{1}{24}$th part of a grain, what then will an inch weigh? not the eight hundred and sixtieth part of a grain.* But the tenth, or perhaps the hundredth, part of an inch of this thread is visible to the naked eye, and then the weight of this portion of it will, in one case, be less than the eight-thousandth, and in the other less than the eighty-thousandth part of a grain.

III. Gold-beaters are able to spread a grain of gold over so large a surface, that, by the assistance of a com-

* The pound avoirdupois is usually divisible into drams as the lowest denomination; but is found that 175 pounds troy are equal to 144 pounds avoirdupois; a pound troy is equal to 5760 grains, therefore 175 pound = 1,008,000 grains: of course 1,008,000, divided by 144 gives 7000 for the number of grains in a pound avoirdupois; hence $\frac{7000}{168000} = \frac{1}{24}$th part of a grain; and the 36th part of this is equal $\frac{1}{24 \times 36} = \frac{1}{864}$ part of a grain; and the hundredth part of this is equal to $\frac{1}{864 \times 100} = \frac{1}{86400}$th part of a grain.

mon microscope, the fifty-millionth part of a grain becomes visible.

IV. The natural divisions of matter are carried to still greater and more surprising lengths. Take a single grain of musk for an example. It will fill every part of the room with a very high scent, without losing, perhaps, a millionth part of its weight; of course the grain is divisible into 6,912,000,000,000,000,000 parts.*

V. I will mention another instance: there are said to be more living animalculæ in the milt of a single cod-fish than human beings in the world, and that they are so minute, that several millions are scarcely bigger than the smallest grain of sand:

——————— So wondrous small,
Were millions join'd, one grain of sand would cover all;
Yet each, within its little bulk, contains
An heart which drives the torrent through the veins.

How small must that heart be, yet it is composed of many still smaller parts; and the globules of fluid, circulating to and from this heart, must be indefinitely smaller than the minute veins and arteries through which they pass.

* Suppose the room to be 20 feet square and 10 feet high, then it will contain 20×20×10 = 4000 cubic feet; in each cubic foot there are 1728 cubic inches; it contains then 6,912,000 cubic inches; if each cubic inch be divided into one million of parts, which will be the case if the inch in length be divided into 100 parts, then the millionth part of a grain of musk will fill 6.912,000× 1,000,000, or 6,912,000,000,000, so many small parts of space; or the grain may be supposed to be divided into 6,912,000,000,000,000,000 parts, as above.

These facts cannot fail to prove to you, that matter is divisible far beyond the limits of our conception.

I need not stop to demonstrate the properties of extension and mobility as belonging to matter: you know that matter, however small, must occupy a certain space, which it does by extension; and, however large, it is capable of being moved, if we possess powers adequate to the task.

We must consider the subject of motion more at large, because upon it much of mechanical philosophy depends. Motion may be defined "A change of place;" and no changes in the universe can take place without motion: of this there are two principal kinds or species: one is the sort of motion by means of which a body is tranferred from one place to another, as the motion of a ball shot from a cannon, or of a vessel moving on the water, or of a carriage on the land. The other kind of motion is of the parts of bodies among themselves: hence plants and animals increase in bulk: hence, also, we account for the composition and decomposition of bodies. A compound metal, as brass, could not exist, if its component parts, copper and zinc, were not put in motion by means of heat, and by being fused they are enabled to unite in one mass. So, likewise, every decomposition is effected: thus, in the distillation of wine, the spirit and the water are separated by means of the motion occasioned by heat. In every process of fermentation and putrefaction, whether by artificial or natural means, there must be motion: sometimes it is the cause, and sometimes the effect of the process.

All matter, by a principle called *inertia*, is said to resist a change of state: that is, a body at rest would remain so for ever; and a body once put in motion must continue so. The first case is obvious, the book on the table would, of itself, never change its place; and a ball put in motion, either by the force of powder, or by being struck with a bat, &c., would continue to move through the air, or to roll on the earth for ever, if it did not meet with resistance from the atmosphere, or from friction, or from gravitation, of which we shall speak hereafter.

EXAMPLE. If I roll a ball along the grass, it will, with a certain force, go a certain distance; but if I roll it on a smooth pavement, with the same force, it will proceed much further, because the friction is less on stone than on grass, and less on ice than on stone; the resistance of the air, and the action of gravity may be considered the same in all the cases.

Hence you will infer, that, to put a body in motion, or to stop one already in motion, there must be sufficient causes: thus, if to give a ball of one pound weight a certain degree of motion, a given force is required; double that force will be required for another ball of two pounds weight. Here we suppose the velocities are equal.

The velocity of motion is measured by the time employed in moving over a certain space, or by the space passed over in a certain time.

EXAMPLE. The velocity of a chaise, travelling ten miles in an hour, is double that of a cart that goes the ten miles in two hours. Or the velocity of a hunter, that runs ten miles in half an hour, is double that of another

horse that would require an hour to pass over the same space.

To ascertain the velocity of any body, we divide the space run over by the time: thus, in the instance just mentioned, the velocity of the hunter is 10 divided by 30, that is at the rate of one mile in three minutes; but the velocity of the other horse will be 10 divided by 60, or one mile in six minutes; and in comparing the velocities of the two horses, we say the velocity of one is double that of the other.

To ascertain the space run over, when the velocity and times are given, we multiply the velocity into the time which will give the space.

EXAMPLE.—What space will be passed over by a ship in 5 hours, that sails at the rate of 9 miles an hour? Answer, $5 \times 9 = 45$ miles.*

A body in motion must, at every instant, tend to some particular point. If it tend always to the same point,

* If the spaces, times, and velocities of a body be denoted by the letters S, T V, we get, as above, $S = T \times V$, and hence we deduce the values of T and V; for $T = \frac{S}{V}$ and $V = \frac{S}{T}$. If there be two bodies moving over unequal spaces in unequal times; the circumstances of the one being denoted by S, T, and V, and those of the other by s, t, v, then we get $s = t \times v$: $t = \frac{s}{v}$ and $v = \frac{s}{t}$ and the velocity of one body will be to that of the other, as the quotients arising from dividing the spaces by the times or $V : v :: \frac{S}{T} : \frac{s}{t}$: if, in one case the space be 1000 yards run over in 5 minutes, and in the other the space be 800 yards passed in 8 minutes, then $V : v :: \frac{1000}{5} : \frac{800}{8} :: 200 : 100$, that is, the velocity of the one is double that of the other. The other theorems may be deduced from this.

the motion will be in a straight line: thus if the ball A, fig. 2, in moving to B, always tends to the same point, its motion will be along the straight line A B. But, if a ball be projected from a cannon, A C, fig. 3, in the direction of A x, the motion will, at first tend towards x, afterwards, by the action of gravity, it will tend towards y, w, v, &c.; so that, in moving from A to B, where it is stopped by the ground, it passes through the curve A a B.

If a body is acted upon by one force only, or by several in the same direction, its motion will be in the same direction in which the moving force acts; the motion of a barge, which a man, standing still, draws to himself, is an instance. If two or more powers, differently directed, act upon it at the same time, it will move in a direction somewhere between them.

This is called the composition of motion, because the two forces are compounded and act in one direction, of which the following is the most simple case:

If a body, A, fig. 4, be acted upon by a force equal to x, in the direction A B, and at the same time, it be acted upon by another force, z, in the direction A C, it will not move in the direction either of A B or A C, but in the diagonal A D; and if the lines A B and A C be made in lengths proportional to the acting forces x and z, and the lines C D and D B be drawn parallel to them, so as to complete the parallelogram A B C D, then the line which the body A will describe will be the diagonal A D. and the length of this line will represent the force with which the body will move.

Instances in nature, in which two forces act in this

way upon bodies, are the planetary bodies; these, by gravitation, tend towards the sun, and, by the projectile force, they have a perpetual tendency to move forward in a straight line; and hence these move in a curve between the two forces. A ship may be acted on in the same way by the wind and tide, and will neither follow the direction of one or the other, but take a line between them both. A kite flying in the air is acted upon by the wind, which would carry it one way, and by the string pulling it another, and it takes a course different from both.

A stone thrown upwards from a ship under sail or from the window of a carriage in motion is impelled forward with the velocity of the vessel or the carriage, as well as upwards in the first case, or sideways in the second by the hand that throws it.

Hence we may understand how it is that our equestrian performers are able to execute such surprising leaps over a garter; all they have to do being to spring to a sufficient height upwards, in which they are assisted by the action of the horse; the motion forwards is given by the horse alone.

In the same way may be explained the many fatal accidents which happen to persons in leaping from a carriage, on the horses taking fright, the velocity with which they reach the ground in such case being compounded of the velocity derived from their own exertions, the effect of gravity, and the velocity of the carriage.

LETTER III.

Why the Planets move in curve lines—Accelerating Motions explained and illustrated—Attraction defined and Illustrated—Instances of the Attraction of Cohesion—Repulsion defined, and familiar Examples of it given.

You ask why the planets and a cannon-ball move in curve lines, and not in a diagonal between the directions of the two forces. The reason is, that the action of gravity in one case, and that of the hand in the other, are not single forces by which a straight line would be formed, but they are *constantly* acting upon the bodies, and drawing them out of the straight line; whereas by the illustration of figure 4, there were supposed only two distinct impulses, viz: that of *x* driving it one way, and *z* impelling it the other. Look to fig. 5; if A be supposed the moon, which by its gravity would fall in one minute along the line A B to 1, and by means of the projectile force, it would, in the same time pass from A to *x*, it will not at the end of the minute be found at 1, or at *x*, but at *a*; and as gravity in the direction A B, is constantly acting upon A, with an accelerating force, and not by a single and uniform impulse, it will describe the curve line A*a*, and not a diagonal right line; so at the end of the second minute it will not be found at *z*, or at 2, but at *b*. Having described the curve line A *a b*, and so of the rest.

I will now illustrate what is meant by an accelerating motion, which is one whose velocity is continually increasing.

EXAMPLE. A marble or bullet let drop from the hand from any height, (as the top of St. Paul's church) is an instance of accelerated motion; for it is found by experiments accurately made, that such a body will in the first second of time fall through a space equal to 16 feet; in the next second, it would fall through 48 feet; and in the third, through 80 feet, and so on. Thus, in three seconds, the body will, by this accelerating motion, pass over 144 feet, whereas if the motion had been uniform it would have gone over only three times 16, or 48 feet.

Accelerated motion has been illustrated by means of the figure of a triangle. Suppose A, fig. 6, to be a falling body, and that it descends to B in the first second of time; the accelerated motions or velocities are expressed by the small lines D E, D E, &c. which are continually increasing in length; and the last or greater velocity, at the end of the second, will be expressed by B C, which is the longest of them all. Now the spaces described in the same time are proportional to the velocities; and the sum of all the spaces described in the small portions of time, is equal to the space described from the beginning of the fall. The whole triangle may be supposed to be formed of these small lines, therefore the space described by a falling body, in the time represented by A B, whether that time be a second or a minute, or any other portion of time, with an uniformly accelerated velocity, of which the greatest is re-

presented by B C, may be fairly represented by the area of the triangle A B C.

Suppose gravity ceased to act, then the space passed over in the next similar portion of time, would be equal to the velocity B C, multiplied by the time A B,* that is, to double the triangle A B C; or (if B F be taken equal, to A B) to the figure B C F G, which is proved by geometry to be equal to twice the triangle A B C; but gravity does not cease to act, therefore the triangle A B C, or its equal C G H must be added to it, of course the space passed over in the second portion of time will be represented by B C H G F, which is equal to three times A B C. By the same mode of reasoning, the space fallen through in the third second of time, will be accurately represented by the space F H M I, which is equal to five times A B C; if then A B C be reckoned 16 feet, as it is found to be by experiments, then the space fallen through in the second portion of time will be equal to $16 \times 3 = 48$, and that in the third portion of time will be $16 \times 5 = 80$, as above.

You will now easily comprehend the law by which uniformly accelerated motions are governed, viz: "The velocities, in each instant, increase, as the odd numbers, 1, 3, 5, 7, 9, 11, &c."

"But the whole spaces described are in proportion to the squares of the times employed:" that is, in twice the time a body will fall through four times the space; in thrice the time, through nine times the space; for by referring to the figure, it will be seen that at the end of the first portion of time there was but one space passed

* See Letter II.

over; at the end of the second, there were four spaces; and at the end of the third, nine; at the end of the fourth there will be sixteen; but 1, 4, 9, 16, are the squares of 1, 2, 3, 4, which represent the times, and it will be found that by adding the odd spaces together, we get others equal to the squares of the numbers representing the times: thus the first space is 1, equal to the square of 1; the first and second together, are $1+3=4$ equal the square of 2, which represents the time employed; and $1+3+5=9$ equal the square of 3, and so on.

Hence we find, the heights from which a body will fall in any given time: thus the height which a body will fall through in six seconds, is the square of 6 multiplied by 16 feet, or $36\times16=576$ feet.

Hence also, we can find the depth of a well, by ascertaining the time which a heavy body takes in falling to the bottom. Suppose I drop a bullet into a deep well, and I find by a stop-watch, that it is 5 seconds before it reaches the bottom, the depth is $25\times16=400$ feet. This rule, however, is accurate only upon the supposition that there was no resistance from the air, which is not the case: the air, especially in all swift motions, produces much resistance, which retards the velocity of a falling body, and of course diminishes the distances passed through in a given time.

I will now proceed to the consideration of the subject of ATTRACTION, by which I mean the tendency that bodies, or the parts of bodies, have to approach each other.

There are several kinds of attraction, as the attraction

of cohesion, the attraction of gravitation, of electricity, of magnetism, and chemical attraction. It is, however, only with the attraction of cohesion and gravitation, that we are at present concerned. I ought to tell you, that by some late experiments of Sir Humphrey Davy, Mr. Oersted, and others, it should seem that the attraction of electricity, chemical attraction, and magnetism, all depend on the same principle, and may probably be traced as effects of the same cause.

We do not know the cause of attraction, but we are all acquainted with its effects; we cannot help seeing that all bodies whatever, have a tendency to the earth, and would fall to it if not supported: thus a stone dropped from the hand, falls to the earth; a bullet projected from a sling or a cannon, will, after the projectile force is spent, fall to the earth; and this tendency is called the *attraction of gravitation.*

By the attraction of cohesion, the parts of bodies are held together. Every body must be made up of parts, and the principle which keeps those parts together, is called the *attraction of cohesion.*

The attraction of cohesion takes place between bodies, only when they are at very small distances from each other. Thus place two globules of mercury, at the eighth of an inch distance from each other, and they will remain for ever at the same distance; but bring them somewhat nearer, and they will unite, and run into one large globule. Bring two leaden bullets together, so as apparently to touch, yet there is no cohesion, but if they are scraped clean, and then squeezed

together with a twist, pretty sharply, they will cohere with much force; and if two flat pieces of lead are pressed together violently, it will be difficult to separate them; the same thing will take place with plates of glass, marble, &c.

Hence it has been inferred, that bodies, in general, which appear to touch each other, are not in actual contact.

Two pieces of cork, placed on a bason of water, may be put at such a distance from each other, and from the sides of the vessel, as to remain where they are placed, but if they are brought within a certain distance from one another, they will attract each other and come together; if within a certain distance from the sides of the vessel, they will be attracted to the vessel. These undoubtedly, are modifications of the attraction of cohesion. So also, is *capillary attraction,* thus called from a Latin word signifying a *hair,* because this kind of attraction was first observed in small tubes, the bores of which, were scarcely larger than to admit a hair.

EXPERIMENT 1. Here is a glass tube, the bore of which is half an inch in diameter, and one also, perhaps, not the fiftieth part so large. I place them both upright in a vessel of water coloured with Brasil wood, or any other substance; in the large one the water rises no higher than the level of the water in the vessel; in the other you will see it rises half an inch higher or more. This effect is produced by what is denominated capillary attraction; and the water will be seen

to rise much higher, as the bores of the tubes are smaller.

Ex. II. Here are two panes of glass joined together at the sides B C, fig. 7, and kept open, by means of a small piece of wax or other substance E, at the opposite side A D. I will immerse them in a dish of coloured water, and the attraction of the glass, at and near the side B C, will cause the fluid to ascend to B, but about the parts D, where the glasses are farthest from one another, it scarcely rises above the level of the water.

Ex. III. This thin smooth board, five or six inches square, I will balance pretty accurately, by means of a scale beam; and then bring the surface of the board to the surface of a pan of water, so as to touch, and it will require a force much greater than its own weight to separate it from the water.

It is by this species of attraction, that salt imbibes water from the air: that a piece of sugar thrown into a tea-cup, containing a small portion of the fluid, instantly imbibes it; that a heap of ashes, sponge, linen, &c. having only a part in water, will, in a short time, become wet throughout.

Some bodies are solid, and some fluid; some are soft, and some hard; some will easily bend, and some are said to be elastic: it is, probably, owing to the different degrees of attraction with which different substances are affected, that they appear in these several states. Some bodies will be found in almost all these states, according to the degree of temperature; thus stick sulphur is solid and brittle, at the usual temperature; with

more heat it may be made soft, and with a still higher temperature it may be melted into a fluid mass. Metals may be either in a fluid or solid state, according to the temperature; some of them, (as the new metals discovered within the last few years by Sir Humphrey Davy and others,) are so soft, that they may be spread with a knife. Hence, heat has a considerable influence upon the cohesive powers of bodies, and if raised to a certain point, it will throw the particles of bodies out of the sphere of each other's attractions. Thus the particles of water cohere, but by raising the heat to the boiling point, they go off in steam: the same is observable in all other bodies.

Some bodies appear to possess a power, which is the reverse of attraction of cohesion, and is denominated repulsion. Water will unite with water, or with spirit, by attraction, but it cannot be mixed with oil; the particles of the two fluids seem to repel one another.

Experiment. If a ball of light wood be dipped in oil, and then thrown in water, the water will recede, so as to form a channel round the ball: this is owing to the repelling force between the bodies.

Water repels most bodies, till they have had time to get wet. A small sewing needle, carefully placed on water will swim. The drops of dew which appear in a fine summer's morning, on cabbage plants, assume a globular form, from the attraction that there is between the particles of water; and upon examination, it will be evident, that the drops do not touch the leaves, because they will roll off without leaving any marks of moisture behind them; which could not happen if there

subsisted any degree of attraction between the water and the leaf.

The repelling force of the particles of a fluid is but small; therefore, if a fluid be divided, the parts easily unite; but if glass, or china, or wood, be broken, the parts will not cohere without being moistened with some other substance; as white lead, glue, &c., because the repulsion is too great to admit of a re-union by themselves alone.

LETTER IV.

Attraction of Gravitation explained—How and by whom first ascertained—inference drawn from it—Experiments—The Deluge accounted for—Laws of Gravitation—Table of Weights according to the Distances—Gravitation between the Earth and other Bodies, mutual—Experiments - In what the Power of Gravity resides—It is an universal Principle.

I HAVE already noticed the motion of bodies, and illustrated accelerated motion, without much reference to the cause which produces it, viz. the attraction of gravitation.

"Attraction of gravitation," or, as it is called in short, "gravity," is the force with which bodies tend towards the centre of the earth. Or, more generally, "It is that power by which distant bodies tend towards each other:" by this principle the planetary bodies tend toward the sun as a centre: and by it all bodies, in the vicinity of the earth, have a tendency to the earth, and will, unless supported, fall in lines nearly perpendicular to its surface.

The power of gravity, for we seem to know nothing about the cause, is the same in all bodies, whether light or heavy; a guinea and a wafer will fall from the same height in the same time, provided it be in a vacuum, that is, in a part of space from which the air is taken away. The mode of performing this I will explain to you hereafter. The fact was ascertained more than a

century ago by the illustrious Sir Isaac Newton. To prove that gravitation is always in proportion to the quantity of matter attracted, he took two pendulums, (the vibrations of which are caused by the attraction of gravitation), of equal lengths, with hollow balls of equal size, in order that the resistance of the air might be the same with respect to both. Within the balls he placed substances very different in weight, but the times of vibration were always the same, though the weights might differ in the proportions of two, or three, or ten to one: hence he inferred that the attraction was proportional to the quantities of matter, because it must require ten times the force to move in the same time, and with the same velocity, a body of ten pounds or ounces, than could be required for a body of one pound, or ounce only. From this fact it is inferred, that all bodies, at equal distances from the earth, will fall with equal velocities. And we have seen in the last letter, that falling bodies, as they approach the earth, do so with increasing velocities. This accelerated motion is produced by the constant power of gravity, which, by adding a new impulse at every instant, gives an additional velocity every moment of time.

You will, perhaps, suppose there may be some exceptions to this general rule; you see, for instance, smoke, steam, feathers, and other light bodies ascend or float about in the air, whereas a marble or a penny-piece would fall instantly to the earth. It was, indeed, formerly thought that smoke, steam, &c. possessed no weight, no gravitating powers; but later experiments have shown that these are equally obedient to the gene-

ral law, as bodies the most dense: and it is owing to the density of the surrounding air that they actually ascend.

EXPERIMENT I. Throw a piece of deal wood, and a piece of copper, or stone, into a pail of water, the one will rise to the top, the other will sink and remain at the bottom: the copper descends because it is heavier than its bulk of water: the wood ascends, and floats on the surface, because it is lighter than an equal bulk of water.

It is the same with regard to smoke and steam; the air is a fluid, and if the smoke or steam be lighter, bulk for bulk, than the surrounding air, it will rise; but if the air were lighter than the smoke it would fall down.

Ex. II. It is easy, as you will see hereafter, to put out a candle in an exhausted receiver of an air-pump, that is, in a receiver in which there is no air, or very little, and, in that case, the smoke will fall to the bottom in the same manner as a piece of metal. This proves that smoke has weight as well as other substances.

You sometimes see smoke ascend majestically in a tall column; sometimes it rises but a short distance, and then spreads abroad on all sides. In the first case, the air is heavier than the smoke, as high as it ascends perpendicularly, and then it meets with air of a density equal to itself, and can ascend no higher.

You will now readily admit that bodies of all kinds, if not impeded by other resisting powers, will fall to the earth, by the attraction of gravitation. By the same power, bodies on every part of the surface of the earth, which you know is of a globular form, are kept steady

on its surface. Because, wherever situated, they tend to the centre of the earth, and, since all tend to the centre, the inhabitants of every part of the globe stand as firm as we do in these islands, though, in point of fact, the feet of different people on the globe are nearly opposite to one another.

Philosophers have sometimes speculated upon the consequences that would result if the point to which bodies naturally tend, were suddenly removed from the centre of the earth; and they imagine that if it was shifted ever so little, it would cause an immediate overflowing of the low lands, on that side of the globe towards which it should approach. Hence the deluge, mentioned in the bible, has been accounted for: it is said that the alteration of this point, to only two or three miles, would be sufficient to lay the tops of the highest hills under water.

You will, however, remember that all places on the earth's surface, are not at equal distances from the centre. The motion of the earth on its axis in 24 hours, which we shall hereafter prove to exist, causes the parts about the equator to swell out, and the parts about the poles to be flattened, more than the other parts of the earth. In other words, it is found that the diameter of the earth across the equator is about 17 miles greater than the diameter from pole to pole.

Another principle relating to the attraction of gravitation, is, that the power is greatest at the surface of the earth, from whence it decreases both upwards and downwards; but not in the same proportion. The force of gravity *upwards* decreases as the *square of the dis-*

tance from the centre. That is, gravity at the surface of the earth, which is about 4000 miles from the centre, is four times more powerful than it would be at double the distace, or 8000 miles, from the centre. To make the matter still plainer, gravity and weight may be taken, in particular circumstances, as synonymous terms. Here is a piece of lead, we say it weighs a pound or sixteen ounces, but if by any means it could be carried 4000 miles above the surface of the earth, it would weigh only $\frac{1}{4}$ of a pound, or four ounces: and if it could be transported to 8000 miles above the earth, which is three times the distance from the centre that the surface is, it would weigh only 1-9th of a pound, or something less than two ounces.

It is demonstrated that the force of gravity downwards decreases as the distance from the surface increases, that is, at one half the distance from the centre to the surface, the same weight already described would weigh only $\frac{1}{2}$ a pound, and so on: the following table will impress the facts stronger on your memory, which is formed upon the supposition that the diameter of the earth is 8000 * miles, and its radius 4000 miles:

A piece of metal, &c. weighing, on the surface of the earth, one pound, will,

at	The centre, weigh	0
	1,000 miles from the centre	$\frac{1}{4}$ pound.
	2,000	$\frac{1}{2}$
	3,000	$\frac{3}{4}$
	4,000	1
	8,000	$\frac{1}{4}$
	12,000	$\frac{1}{9}$

* The diameter of the earth is 7930 miles.

And at the distance of the moon from the earth, which is 240,000 miles, it would weigh only $\frac{1}{3600}$th part of a pound, because the distance being 60 times farther from the centre of the earth than the surface is, and the force of gravity decreasing as the squares of the distance, it will be as 1 to $\frac{1}{60 \times 60}$ or 1 : $\frac{1}{3600}$.

Another fact, to which I would draw your attention, is, that as all bodies gravitate towards the earth, so the earth itself gravitates equally towards all bodies. It is true we see bodies fall to the earth, but we do not see the earth move towards those falling bodies; the reason is this: the earth is immensely large, compared with any body which is on its surface, and therefore its motion must be infinitely small, in comparison of the motion of falling bodies upon it. The same is applicable to the gravitation of bodies among themselves; all bodies have an attraction for one another, but the attraction of the earth preponderates so much above all other attractions near its surface, as to prevent the other attractions from being noticed. I will illustrate what I mean by an experiment.

EXPERIMENT I. On this vessel of water, I place two pieces of cork, one large and another small, I bring them within the distance of one another's attraction, and you will see the small piece move as much faster than the large one, as it is less than that.

Had they contained equal quantities of matter, they would have met in the centre point between the two. In this case the attraction of the earth has nothing to do

with their motions, because they are supported by the water from falling towards the centre of the earth.

Ex. II. If I were to let two balls fall from the top of a high tower, or from the dome of St. Paul's, at a small distance apart, as a yard, though they have an attraction for one another, it will be as nothing, when compared with the attraction by which they are drawn to the earth, and consequently, the tendency which they mutually have of approaching one another, will not be perceived in the fall.

Ex. III. If, however, any two bodies were placed in free space, and out of the earth's attraction, they would, in that case, assuredly approach each other, in the same manner as the corks on the water did, and that with an increased velocity as they approached each other. If the bodies contained equal quantities of matter, they would meet in the middle point between the two; but if they were unequal, they would meet as much nearer the larger one, as that contained a greater quantity of matter than the other. Hence, though the earth ought to move towards falling bodies, as well as they move to it, yet as the earth is so many million of times larger than any thing belonging to it, the point in which a falling body and the earth would meet, is removed only to an indefinitely small distance from its surface, a distance much too minute to be conceived by the human imagination.

I ought to inform you, while on the subject of gravitation, that it is not any thing at the centre of the earth that causes the attraction of gravitation, but the whole

body of the earth itself; and if the earth contained more or less matter than it does, the laws of gravitation would be different from what they now are. Even high mountains will attract bodies to themselves. The mountain of Schehallien, in Scotland, was selected by Dr. Maskelyne for the purpose of making the experiment. A telescope was brought to the south side of the mountain, and pointed to a star in the zenith—to the object end was hung a plumb-line, so as at the same time to pass over a fine dot near the eye end. The telescope was then removed to the north side of the mountain, and pointed to the same star, when it was found that the plumb-line, instead of passing over the dot, as in the former situation, was deflected towards the mountain. This experiment was several times repeated with the same result, plainly shewing, that the mass of matter contained in the mountain attracted the weight of the plumb-line towards it, causing it to deviate in the first situation to the northward and in the second to the southward of the true perpendicular. From this and other experiments of a similar nature, it is inferred that the whole body of earth is the attracting body, and the cause of weight. Gravity is an universal principle; it is that, which, in the hands of the Creator, first formed, and still maintains the earth in a globular shape: it is that which preserves every thing animate and inanimate on its surface; by this we stand fast on all sides of the globe, for the thickest mass of earth is directly under our feet, whatever be our position, whether in Great Britain, or on the continents of Europe, Asia, Africa, or America, and the thickest mass has the most powerful attraction.

LETTER V.

First Law of Motion exemplified—Second Law of Motion explained—Third Law of Motion illustrated—Collision of elastic and non-elastic Bodies—Facts and Experiments relating to the collision of Bodies—Curious Circumstance connected with the inertia of Matter—Principle of the Vibrations of Pendulums.

MY YOUNG FRIEND,

In reasoning on natural philosophy, there are three laws of motion, which I will state and illustrate, and which you should not only comprehend, but commit to memory. The first is,

"That every body will continue in its state of rest, or uniform motion, in a right line, until it is compelled by some external force to change its state."

A bullet, discharged from a gun, would continue its motion for ever, if there were no external obstacles arising from the resistance of the air, and the action of gravitation; the former is every instant diminishing its motion; and the latter is continually bringing it to the earth, so that, from what we have seen, though it may be projected horizontally, yet it does not continue in a state of motion, in a right line, for a single instant, but describes a curve till it reach the earth, and, by comparing what we have discussed before, respecting the combination of forces (page 13 and 14) you will see that it will reach the ground precisely at the same moment, as if it

had fallen from the hand in a perpendicular direction. A top, once put in motion, would revolve for ever, if it were not impeded by the air and the friction produced by the peg on the plane on which it moves. It is by this law that the heavenly bodies preserve their progressive motions undiminished, because they travel in regions in which there is no resistance from a fluid atmosphere, and because their centrifugal and centripetal motions, that is, their motions occasioned by a projectile force, and by an attraction to a centre, are adjusted and nicely balanced.

Secondly. "The change of motion is always proportional to the moving force by which it is produced, and it is made in the line of direction in which that force is impressed."

A cannon ball will be projected to a certain distance with a certain charge of powder, but if more or less powder is used, the ball will proceed farther in the former case, and not so far in the latter. If I strike a cricket-ball so as to make it go fifty yards, and then strike it with double or triple that force, it will, other circumstances remaining the same, go nearly double or triple the distance. I say nearly, because the resistance of the air has a much greater effect on swift than on slow motions. Again, the motion is made in the line of direction in which the force is impressed: a vessel at sea, where there are no tides to prevent, will obey the force of the wind, and will go directly before it. But if the vessel at A, fig. 8, be going down a current, A B, due south, at the rate of six miles an hour, and the wind in the direction A D, due East, drive it at the rate of

eight miles an hour, it will proceed neither north nor east, but between them both, along the line A C; and it will, at the end of the hour, if the current and the wind continue the same, be found at the point C, and as the line A C is longer than the line A B or A D, it will have sailed further, by the joint action of the two forces, than it could by either of them separately, because the line A C is 10 miles,* whereas the line A D is only eight miles.

Thirdly. "Action and re-action are always equal and contrary." That is, the action of two bodies on each other is always equal, but in contrary directions. If I press with my hand on one scale of a balance, to keep it in equilibrio with a seven pound weight in the opposite scale; the hand is pressed by the scale upwards as much as the hand presses the scale downwards; that is, in both cases the pressure is equal to seven pounds. If, standing in one boat, I draw, by means of a cord, another of equal weight to me, they will both move and meet in a point half way between the two. Here action and re-action are equal and in contrary directions. If I strike the table with my hand, the action of the table against the hand is as great as that of the hand against the table. A horse, drawing a load, is as much drawn back by the load, as he advances with it, that is, his progress is so much impeded, for with the same quantity of exertion, he would be able to proceed

* The length A C, is found by squaring the lengths of A D and A B, and taking the square root of the sum: thus—
$\sqrt{8^2+6^2}=\sqrt{64+36}=\sqrt{100}=10$.

much farther, without the load than he can with it; and, if the load be increased till it is precisely equal to the strength of the horse, it will remain at rest, though the whole force of the animal be in action.

From this law of motion, we learn in what manner a bird, by the stroke of its wings, is able to support the weight of its body. If the force, with which it strikes the air below, is equal to the weight of its body, then the bird will, as it were, rest between the two forces. If the force of the stroke is *greater* than its weight, the bird will *rise* with the difference of these two forces: and, if the stroke be *less* than its weight, then it will *sink* with the difference.

Hence I may lead you to the consideration of the collision of bodies elastic and non-elastic, which depends chiefly on the third law of motion. An elastic body is that which changes its figure, and yields to any impulse or pressure, but endeavours, by its own nature and force, to return to the same again. If I bend a piece of cane, by bringing the ends near together, it will, the moment I let the ends go, endeavour, by its own force, to attain its original straightness: the same may be said of a slip of steel, and of many kinds of wood, to a certain degree. In all such cases, the body, bent out of its natural position, makes an effort to set itself at liberty; this is owing to the principle of elasticity, and the force of the effort is measured by the power necessary to keep it in its bended state.* You have seen a bladder blown up with air; by pressure, with the finger, you will make a dent on it, but remove the finger,

and it instantly recovers its former state. All bodies, with which we are acquainted, partake of the property of elasticity, some in a greater and others in a less degree; none, perhaps, are so perfectly elastic, as to restore themselves with a force equal to that with which they are compressed. The following facts are well deserving a place in your memory, and the illustrations may tend to fix them there :

1. A perfectly elastic body, if there be such a thing, endeavours to restore itself with the *same* force with which it is pressed or bent

2. An elastic body exerts its force equally towards all sides, though the effect is chiefly found on that side on which the resistance is weakest; this is evident in the firing a gun, when the elastic fluid, generated by the powder, exerts itself on all sides of the barrel, but its effect is visible only at the mouth of the gun, because the resistance of the air in that direction, is nothing compared with the resistance of the sides of the barrel.

3. Elastic bodies, however struck or impelled, rebound in the same manner: thus, a bell, which is very elastic, yields the same musical sound, in whatever manner or on whatever part it is struck; and a ball, marble, &c., rebounds from a plane in the same kind of angle in which it is struck, making what is called the angle of incidence, equal to the angle of reflection.

4. The elastic properties of some bodies seem to differ according to their greater or less degree of density: thus, metals are rendered more dense and more elastic by being hammered; cold condenses solid bodies, and

makes them more elastic; but air, steam, and other elastic fluids, are expanded by heat, and rendered more elastic.

With regard to the collision of bodies, I must observe, that according to the third law of motion, if two bodies strike each other, their motions are equally affected, and their collision produces equal changes, but in contrary directions.

EXPERIMENT I. Let two balls D and B, (fig 9), be suspended from a common centre A, and let D be coloured over with some fluid, and, while it is wet, let the two be brought into contact; a small mark will be made on the dry ball; but if the coloured one be raised to a certain height, and then suffered to fall against the other, the impression marked on the dry ball, will be much larger than when it was brought into mere contact only, which proves that the balls were indented by the stroke, and their appearance after the stroke shews that by their natural elasticity, they have recovered their original form.

EX. II. Let two equal ivory balls, B and C, be suspended at A, and, when C is at rest, let B fall upon it, and it will by the collision lose the whole of the motion which it has acquired in its descent through the air B C, and the ball C will be driven up to D, in the same manner as B would have been carried to that point by its acquired velocity, if it had not been obstracted by C.

Hence the striking body will communicate the whole of its motion to the other, and afterwards remain at rest.

EX. III. Let three balls, *a*, *b*, *c*, fig. 10, be hung from adjoining centres, and *c* be drawn a little out of the perpendicular, and suffered to fall upon *b*, then will

c and *b* become stationary, and *a* will be driven to the position *o*, the distance through which *c* fell upon *b*.

Ex. IV. Let any number of balls hang on adjoining centres, so as, in the quiescent state, to touch each other, if the outside one be drawn aside, and let fall upon the others, the outside ball, on the opposite side, will be driven off, while the rest remain stationary.

Ex. V. If two of the balls were suffered to fall at the same time, but at a small distance from each other, the middle balls would remain at rest, and the motion would pass through their centres to the two remote balls. All these experiments will prove that action and re-action are equal and in contrary directions.

Another circumstance, mentioned by authors, in connection with this subject, is deserving of your attention, and which depends upon the third law of motion, and on the inertia of matter. If a blacksmith strike his anvil with a hammer, action and re-action are equal, the anvil strikes the hammer as forcibly as the hammer strikes the anvil. If the anvil be large enough a man might place it on his breast, and suffer another person to strike it with all his force, without sustaining any injury, because the vis inertiæ of the anvil resists the force of the blow. But if the anvil were small, as only a few pounds in weight, the blow would be fatal.

I shall finish this letter with a short account of the principle of pendulums.

A pendulum is a heavy body suspended by a string or small wire, which moves about a point as its centre.

When this weight is put in motion, it will descend through one half of an arc by its own gravity, and as-

cend the other half by means of the velocity which it has acquired in its descent.

Suppose a body P, (fig. 11), to be suspended by a line, from a centre C, if it be raised to D, and then let fall, it will descend through the arc D P by its gravity, and in falling it acquires such a velocity as it would obtain in falling from E to P. At P, if it were at liberty, it would, by the first law of motion, fly off in the right line P F, but, being retained by the string, it ascends through the arc P B to B, here its motion is spent, and it returns to D, and would thus continue to move for ever, if it were not retarded by the friction which the cord has on the hook C, and by the resistance of the air; these impede its motion, and each vibration is less than the former, till at length the pendulum comes to rest in the position C P.

The vibrations of the same pendulum, whether small or great, are performed in equal times nearly, that is, whether the weight P be raised to X or to D, the vibrations will be performed in equal times.

The point C, on which the pendulum swings, is called the point of suspension. The longer the pendulum, the slower are its vibrations, and the contrary. A pendulum that vibrates seconds in this country, is 39.2 inches, nearly, that is, the length from the point of suspension C, to the centre of vibration, or the centre of the body P, is 39.2 inches. But a pendulum 40 inches long would vibrate slower, and one 30 inches long would vibrate faster.

The vibrations of pendulums are governed by the law of gravity, to which I have already referred: and

"The time of the vibration of pendulums, is as the square roots of their lengths."* Thus, as a pendulum 39.2 inches, vibrates seconds, to make one that shall vibrate once in two seconds, it must be 4 times as long, or 156.8, and to make one vibrate once in three seconds only, it must be nine times 39.2 inches, or 352.8 inches.

Again, to make a pendulum vibrate half seconds, as is the case in most table clocks, it must be only $\frac{1}{4}$ the length of the pendulum that vibrates seconds, or $\frac{39.2}{4}=9.8$.

If, instead of a line and weight at the end, a pendulum be made of metal, or other substance, of one uniform thickness, it must be one third longer than the common pendulum, and the centre of vibration in the weight will be the centre of percussion in the rod. By the centre of percussion, I mean that part of the rod which produces the greatest impression in striking a blow.

You will not forget that pendulums of the same length, vibrate slower the nearer they are to the equator, because gravity, the cause on which the vibrations depend, is less at the equator than it is nearer to the poles. Therefore, a clock that keeps accurate time in London, with a pendulum 39.2 inches long, would go too slow

* Suppose T and t represent the times, and L l represent the lengths of the pendulums, then we say,

$T : t :: \sqrt{L} : \sqrt{l}$.

or

$T^2 : t^2 :: L : l$ and if $T=1$ and $t=\frac{1}{2}$: and $L=39.2$, then $l=\frac{1}{4}\times 39.2=9.8$. But if $T=1$ and $t=2$, and $L=39.2$, then $l=39.2\times 4=156.8$.

at the equator, and too fast towards the poles; for the motion of the pendulum depends on the action of gravity, in the same manner as that of any other falling body, and it is ascertained that a body will fall 313 inches at Spitzbergen, in the same time that it falls 312 at Quito, which is situated near the equator.

LETTER VI.

On the Centre of Gravity—Experiments—Reason why high Buildings, leaning out of the perpendicular, stand firm—How Rope-dancers balance themselves—How to find the Centres of Gravity mechanically—This Knowledge very useful in many Situations in Life—Operations of the loaded Cylinder, double Cone, rolling Lamp, and Mariner's Compass, explained.

EVERY body has a "centre of gravity," or a point in which its weight is supposed to be collected, or in which it may be suspended in any direction. Try to balance the parlour poker on your finger, and when you have brought it into a state of equilibrium, the part which rests on the finger is its centre of gravity. If this point be supported the whole body will be at rest.

A line drawn from the centre of gravity, perpendicular to the horizon, is called the line of direction; and if the centre of gravity be not supported, the body will, unless prevented by some obstacles, fall to the earth in this line.

When the line of direction falls within the base of any body, that body will stand; but when it falls without the base, the body will fall. I will now illustrate this subject with experiments.

EXPERIMENT I. I place a piece of wood, A, (fig. 12.) on the edge of the table, and from the pin *a*, at its centre of gravity, I hang a little weight, *b*, and it will be seen that the line of direction *a b* falls within the base,

and, therefore, though the wood leans, yet it stands secure. I will now put another piece of wood, B, of a similar shape, upon it. This raises the centre of gravity to *c*; from which point if a weight be hung, it will be seen that the line of direction *c x*, will fall out of the base, and the body must fall.

Hence you may see the reason why towers, steeples, walls, &c. may stand a good deal out of the perpendicular, and yet be very firm; because, though leaning, as that of the tower of Pisa, 15 or 16 feet out of the perpendicular, still a line drawn from *c*, the centre of gravity, (fig. 13), falls within the base A B, and therefore, so long as the cement endures firm, the building will not fall.

Hence you learn why a conical body, as a sugarloaf, stands so firm on its base; for the top being small, compared with the base, the centre of gravity is thrown very low: and in an upright or perpendicular cone, the line of direction falls in the middle of the base, which is another fundamental property of steadiness in bodies. For the broader the base, and the nearer the line of direction is to the middle of it, the more firmly does a body stand. Whereas, tall bodies, with pointed or narrow bases, can with difficulty, be made to keep their upright position, as you may experience, by endeavouring to balance on your finger a walking-stick. On a similar account, you must understand the difficulty which rope and wire dancers have in balancing themselves on so very small bases, and the motive which induces them to make use of long poles, the ends of which are loaded with lead. The man holds the pole across the rope on

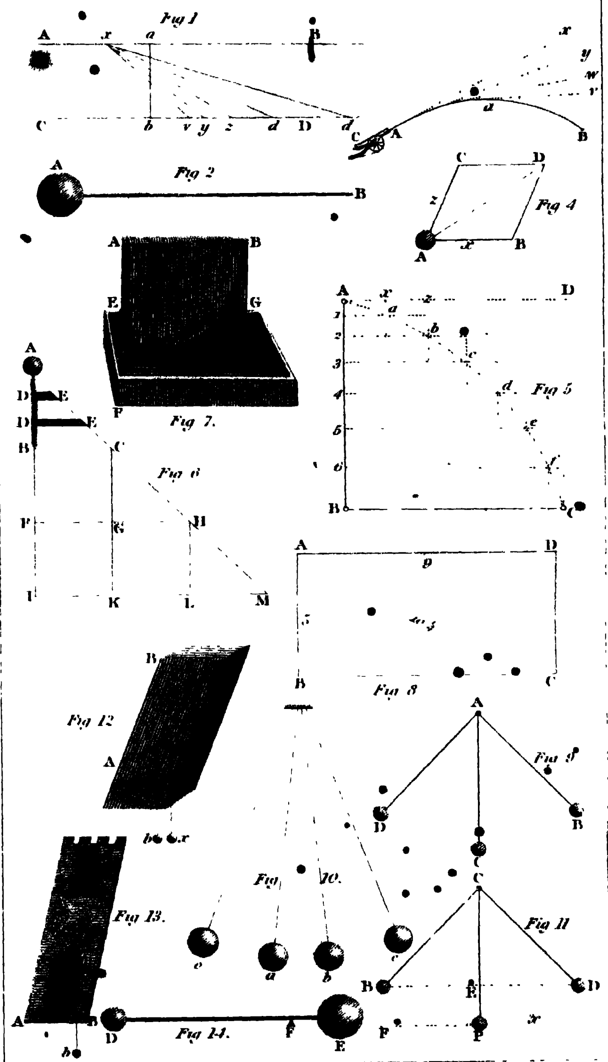
which he moves, and keeps his eye steadily fixed upon some object parallel to the rope, by which he can easily judge when his centre of gravity tends to either side of the rope, and by pushing the pole a little to the other side he can keep his centre of gravity over the base.

I will now proceed to shew you how to find the centres of gravity of different bodies mechanically.

EXPERIMENT I. If two bodies of similar shape, as balls, and of equal weights, be fastened to the extremities of a rod of uniform thickness, the centre of gravity will be in the middle of the rod. If the bodies D and E, (fig. 14), be of unequal weights, the centre of gravity, F, will be as much nearer to the larger than to the smaller body, as that body is heavier than the other; thus if E weigh four pounds or ounces, and D only one, then the length E F will be one, and F D will be 4 : or it may be represented thus, E : D : : D F : E F, or E : D : : 4 : 1, that is, the lengths of the arms, from the point of suspension, will be inversely proportional to the weights.

In the motion of a chain-shot, if one ball be heavier than the other, the two balls will perform a circuit round each other as they fly, and their centre of gravity will describe a regular curve. So the earth and moon, in their journey about the sun, move round one another, and neither of them describe a regular curve round that luminary, but the centre of gravity of the two performs the ellipse.

EX. II. The centre of gravity in any plane, may be found in this way. Let C B D L, (fig. 15, Plate II.), be the plane figure, which is suspended freely on the



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hook A, and apply a plumb line to the hook A, which will pass over the centre of gravity, somewhere in A B, which falls beneath the centre of suspension; this line is to be marked, and the body is then to be suspended by some other point at C, and where the lines C D and A B cross each other in E, is the centre of gravity.

When the centre of gravity coincides with the centre of motion, as in some scale beams, then the body will rest in any position, without tending to fall lower, or to return to its original situation.

When the centre of gravity C, fig. 16, is situated vertically over a fixed point, it cannot move without descending; and when it is under a fixed point, fig. 17, it cannot move without ascending. Which facts, when compared with the figures referred to, will show you the reason of placing the moveable handles of a vessel, as a pail, bucket, &c. at its upper part, in order that the centre of suspension may be always above the centre of gravity. If they were fixed much lower, the vessel would be perpetually liable to overset.

I have already shewn you that the broader the base of a body, the lower will be the centre of gravity, and the firmer will that body stand, which points out the necessity that there is for great attention in loading carts and waggons with comparatively light goods. A waggon, employed in carrying lead or iron, cannot be easily overset, but one loaded very high with hay, or straw, or hops, must be done by an able hand, to move safely over rough roads. A waggon or carriage, of any kind, will always recover its position, provided the centre of gravity, c, remain within a vertical line, passing through

the point of contact of the lower wheel and the ground: this is the case with B, fig. 18, and therefore there is no danger of an overthrow; but in A the centre of gravity is without the line, and it must, in such a position, go over.

If the velocity of the carriage is great, the danger is proportionably great, because the wheel which is elevated might be lifted off the ground by the momentum, and the centre of gravity must thus be carried beyond the vertical line, by means of an obstacle which would not overset the waggon if it had been moving at a moderate rate.

If a person be in a carriage, that part on which he sits may be considered as the place of his weight, provided he remain in an erect position; but as he will not be able, when in very swift motion, to maintain a perfectly erect posture, the centre of gravity of the carriage, with its passengers, is to be regarded as something higher than the seat.

From what has been said, you will understand the reason of a very common experiment, viz. the suspension of a pail of water, or any other weight, M. fig. 20, on a stick, S, resting on the end of a table, T: another stick, x, being employed, as in the figure, to keep the pail at such a distance from the end of the first, that the centre of gravity of the weight M, may be under the table. Though the weight is suspended by the handle, yet if the handle began to descend, the centre of gravity must rise, which it cannot: therefore the whole will retain its position and remain at rest.

The ascent of a loaded cylinder on an inclined plane,

fig. 21, and the motion of a double cone, fig. 22, up an inclined plane, formed of wires, or bars, apart from one another, may be explained on the same principle, viz. the endeavour which the centre of gravity makes to descend. In fig. 21, though the cylinder will move up the plane P N, yet the centre of gravity descends. This is also the case with the double cone, the centre of which descends as the opening of the legs of the plane increases.

Before I quit the subject, it may be observed that the equilibrium of animals may be explained upon the principle of the centre of gravity. When a person stands on one foot, and leans somewhat forward, or in the attitude which is usually exhibited in the statues of Mercury, the other foot is elevated behind, in order to bring the centre of gravity of the body, so as to be vertically over some part of the foot on which he stands. When we rise from our seat, we generally bend forwards and draw our feet inwards, in order to bring the point of support into, or near, the vertical line, passing through the centre of gravity. For the same reason a man, carrying a burden on his back, leans forward, and backward if the weight is to be carried on his breast. If the load be placed on one shoulder, he leans to the other. When we slip or stumble with one foot, we naturally extend the opposite arm, making the same use of it as the rope-dancer does of his pole.

The rolling candlestick, fig. 23, keeps the candle always upright, though put down in any position, or even rolled on the floor, for a weight, A, beneath the candle, and lower than the two centres of suspension, *c c d d*,

will keep the candle perpendicular, the tendency of the centre of gravity being always to fall beneath the centre of suspension. The circle *d c d c*, hangs on two points, *d d*; and the inner circle, on which is fixed the light and weight, hangs on that circle by the pivots *c c*, at right angles to the pivots *d* and *d*. In fixing the mariner's compass, to prevent any deviation by the motion of the ship, these circles are called gimbals, and the compass being hung on the inner circle, is always kept horizontal, let the vessel roll as it will, and, of course, the magnetic needle, can traverse as freely as if its point of suspension were fixed on the shore.

The knowledge of the centre of gravity will enable you to explain the principle and structure of many toys put into the hands of children, as the tumbler, the rope-dancer, balancer, &c. In all cases, remembr, the centre of gravity tends to the centre of the earth, and will never be at rest, if left freely to itself, till it gets to the nearest point possible to it.

LETTER VII.

Of the mechanical Powers—Momentum defined and explained—Experiments—Mechanical Powers enumerated—The Principle of the Lever explained—Construction of the Steelyard—Uses of a Lever of the first kind—What domestic Instruments to be referred to a Lever of the second kind—What things are explained by a Lever of the third kind—The Hammer Lever.

I SHALL now proceed to explain and illustrate the nature and use of the mechanical powers, one of the great objects of which is the removal of great weights, that is, in other words, overcoming the force of gravity. In this letter I shall have occasion to use the word MOMENTUM, or moving force of a body, which is measured by the weight of the body multiplied into its velocity. You may place, without any risk, a weight of six or seven pounds, for instance, on a china plate; but if you let the same weight, or one much less, fall from your hand, though only an inch or two, it will dash it to pieces. The china, in the one case, has only the weight to sustain, in the other it has the moving force, or momentum, to resist, that is, the velocity multiplied into the weight is to be considered as the force.

EXPERIMENT I. If a roller or ball, as *a*, (fig. 24. plate II.) lean against the small block of wood *b*, they will both remain at rest, but if *a* be carried up the inclined plane A B, and suffered to roll down against the block, it will be overset. Here again you perceive the difference be-

tween weight and momentum, and you must not forget that the momentum is estimated by the quantity of matter multiplied into its quantity of motion; of course, by increasing the velocity you increase the momentum of a moving body. Hence,

Ex. II. Cannon balls will do much more mischief than the battering rams of ancient times: suppose the weight of a ram to be 20,000 pounds, and to move at the rate of 1 foot in a second; and the weight of a cannon ball to be 24 pounds, and to move at the rate of 1000 feet in a second then the momentum, or moving force of the ram, will be $20,000 \times 1 = 20,000$, and that of the cannon ball will be $24 \times 1,000 = 24,000$; of course the effect of the latter will be $\frac{1}{5}$th greater than that of the former. Thus you see a small body may have a greater momentum than a large one, provided the velocity of the small one be made to compensate for the greater quantity of matter in the other.

There are reckoned seven mechanical powers, viz. the *Lever*; *Wheel and Axis*; *Wheel and Pinion*; *Pulley*; *Inclined Plane*; *Wedge*, and *Screw*. By these simple instruments man is enabled to raise great weights, and to overcome such resistances as would baffle his natural strength; and from the combination of some or all of them, compound machines of every kind are formed. Indeed the most complex machinery may, in some way or other, be resolved into the simple mechanical powers.

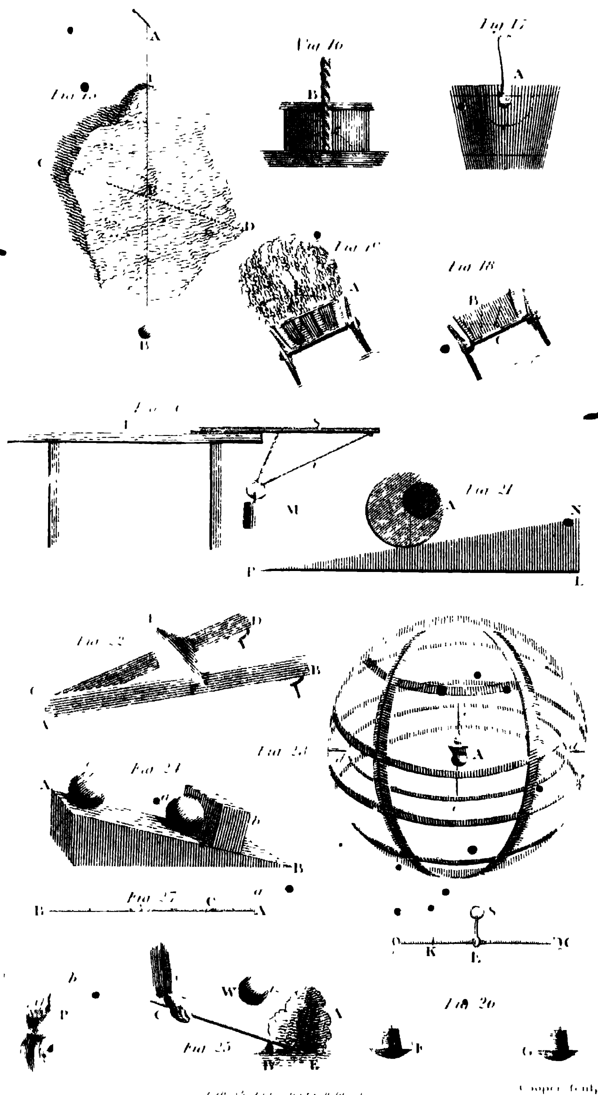
The lever is the most simple of all the mechanic powers; it may be made of any shape, and of any strong substance, as wood or iron. There are three varieties of the lever: the first is represented by figure 23, plate II.

which shows its operation in moving a heavy weight A. The support, B, is called the fulcrum, or centre of motion, because the bar C E, is supported by it and turns upon it. Power is gained by a lever of this kind, in proportion as the arm C B is longer than the arm B E. If the two arms were equal, no advantage would be gained, but if C B be 4 times, 10 times, &c. longer than B C, then a person at C would be able to move 4 times, or 10 times more than he could with his natural strength. It is then, as you observe in the figure, the principle of this species of lever, to have the weight at one end, the power at the other, and the fulcrum between the two.

EXPERIMENT I. The beam of a pair of common scales is a lever of the first kind, with equal arms; in this case no advantage is gained or required. If two bodies, F and G, fig. 26, of equal weight, be suspended at equal distances from the fulcrum, the centre of gravity E, will rest beneath the point of suspension S, because the weights and distances being equal, the moving forces must be equal, and neither end can preponderate; but if the scale F be moved to K, the centre of gravity E, moves towards G, and falls beyond the point of suspension, and becomes unsupported; of course the end of the beam C, descends, because the centre of gravity is always impelled towards the line of suspension. This shews that a smaller weight than G would balance F, when brought into the position K; and on this principle the steel-yard acts, for if the longer arm were equal to six or eight times the length of the shorter, then a body, suspended from C, would balance six or eight times its weight suspended from K.

In all cases of the lever, to obtain an equilibrium between the weight and the power, the momentum of the weight must be equal to the momentum of the power.

The velocity of a body is measured by the space passed over in a given time. In fig. 27, the arm B C is four times the length of A C; therefore, in moving from the position A B to that of *a b*, the point B will move over the space B *b*, and the point A will move over the space A *a*; but B *b* is four times greater than A *a*; therefore, the velocities being as the spaces passed over in the same time, the velocity of B will be four times greater than that of A: of course if W weighs 12 pounds, a power, P, of a pound, will balance it, because the momentum $W = 12 \times 1$, and that of the power $P = 3 \times 4$. Here you must observe, that what is gained in power is lost in space, that is, if I would gain a power of 6, or, by means of a lever, move a weight six times heavier than I can by my natural strength, then, to raise the weight one inch or one foot, my hand must pass over six inches or six feet. This is what writers on the subject mean when they say "that what we gain in power we lose in time," because supposing, in both cases, the velocity to be the same, then as much more time is occupied in performing a mechanical operation as there is power gained. If, for instance, I can raise four score pounds to a certain height in one minute, and I want to raise four hundred pounds to the same height by means of machinery, as the lever, I shall require five minutes to accomplish it in, so that I might, in truth, if the 400 pounds could have been divided into five parts, have done the same in an equal portion of time, by five successive manual exertions. But to return to the steel-yard.



A C, (fig. 28, plate III.) the short arm and scale, (sometimes a hook is used instead of a scale) is made to balance the longer one B C, which is divided into parts C 1; 1, 2; 2, 3, &c., each equal to A C; and by this contrivance, a single pound, P, will weigh any number of pounds of meat, &c., in the scale S, as the long arm extends to; thus, if the balance be in equilibro in the position of the figure, the substance in the scale will weigh three pounds; if, when the weight is pushed on to 4, 5, 6, &c., there is an equilibrium, then the substance will be found to weigh 4, 5, 6 pounds, &c. It will be evident, on a little reflection, that the points in the long arm of the lever, marked 2, 3, 4, 5, &c., will move over twice, thrice, four times, &c. as much space as the point A in the short arm.

By dividing the spaces in the long arm into halves, quarters, and sixteenths, which is easily done, the steel-yard will serve for weighing any commodities with accuracy, to half-pounds, quarters, and ounces.

You will observe that, in all cases of the lever, the parts will remain in equilibrio, when the weight, or resistance, at one end, multiplied into the length of the arm to which it is attached, is equal to the power multiplied into the other.

A poker, in the act of stirring the fire, is a lever of this kind, the bar on which it rests is the fulcrum, and the coal to be raised, forms the resistance, or weight, and the hand the power. Put the poker into the fire, a small part only goes into the grate, and there it will, perhaps, rest, or remain in equilibrio, because the weight of the coal, against the short end, balances the

weight of that part of the poker which is on the other side of the bar; and a small force, at the bright end of the poker, will easily raise the fire.

To this kind of lever are to be referred a pair of scissars, which is made up of two levers acting against one another, and the pin, which keeps the parts together, is the fulcrum or centre of motion, round which they move in the act of opening and shutting: the same may be said of snuffers, pincers, &c.

As a mechanical power, the lever of the first kind is chiefly used for loosening large stones; or for raising great weights to small heights in order to get ropes under them.

The lever of the second kind, fig. 29, is when the weight W, is between the fulcrum and the power. The common application of this lever, is when a large block of stone is to be forced forwards with an iron crow, the point of the instrument is stuck in the ground, which becomes the fulcrum; the other end, that is acted upon, is the power, that is, the strength of men; and the stone to be moved is the resistance or weight.

By referring to the figure, you will at once see that power or advantage is gained in proportion as the distance of the power P, is greater than the distance of the weight W, from the fulcrum. In the present instance, the advantage gained is as five to one, because the point B, passes over five times as much space as the point A, that is, the hand will move with the velocity 5, but the weight with the velocity 1.

Look round your room and consider what those things are that may be referred to levers of the second kind.

Every door acts as a lever, the hinges are the centres of motion, or fulcrum, the whole door is the weight, and the hand applied to the lock, or latch, is the power. Fix a temporary handle, as a gimblet, within two or three inches of that side near the hinges, and you will feel how much less easy you can move the door than when you attempt the same by the proper handle. If you wish to turn round the couch, you lay hold of one end, while the other remains nearly in its original position, the latter is the fulcrum, the couch is the weight, and the power is applied to the other end. Many persons who work in wood, as coopers and patten-makers, use cutting knives, fixed at one end, which end is the fulcrum, or centre of motion, the wood to be cut the resistance, and the hand the power. Common chaff-cutters act on this principle; so do nut-crackers, and the rudders of ships. In a rudder the water is the fulcrum, the vessel the weight, or resistance, and the hand the power. Masts of ships are levers of this kind, the bottom of the vessel in which they are fixed is the fulcrum, the ship the weight, and the wind, acting against the sail, is the moving power.

Two men carrying a barrel, or other weight, may, by this principle, place the barrel at such a point on the pole, as to adapt it to the strength of each man, supposing one to be much weaker than the other. Here the strongest man must be considered the fulcrum.

A lever of the third kind has the fulcrum C, fig. 30, at one end, the weight W, at the other, and the power P, somewhere between the prop and the weight. You will easily perceive that the weight, being farther from

the centre of motion than the power, must pass through more space than that; of course the power must be greater than the weight, and as much greater as the distance of the weight from the prop exceeds the distance of the power from it: in the present case, a weight, W, of 3 pounds, hanging at A, would require the exertion of a force at B equal to 5 pounds. Here the weight, in rising and falling, goes through a larger space, and has a greater velocity than the power, and, therefore, no mechanical advantage is gained by this kind of lever, and it is very rarely used: wool-shears, acting by pressure in the middle, is a lever of this description. A ladder fixed against a wall at one end, and raised by the strength of a man's arms into a perpendicular situation, is by the application of the principle of a lever of this kind. But the limbs of the animal creation, particularly of man, give the most evident illustration of this principle. When I extend my arm to raise a weight from the ground, or table, the operation is effected by means of muscles coming from the shoulder blade, and terminating about one tenth as far below the elbow as the hand is: see fig. 31. The elbow, D, is the centre of motion, round which the arm moves; therefore, according to the principle laid down, the muscles must exert a force ten times as great as the weight raised. In general the bones are levers, the joints of them the *fulcra*, and the muscles the power which gives motion to the whole. At first view this may appear a disadvantage, but what is lost in power is gained in velocity, and thus the human figure is better adapted to the various functions which it has to perform.

Some writers have described a fourth kind of lever,

of which a hammer, in the act of drawing a nail, is a fit representation, and which does not differ from a lever of the first species, but in the form.

EXPERIMENT. Let A C B, fig. 32, represent a lever of this kind, bended at C, which is a fulcrum; P is the power, acting upon the longer arm A C, by means of the cord A D, going over the pulley D; and the weight, W, acts upon the shorter arm C B. A C is five times as long as C B, and will, with a power P, of 1 pound, balance a force of 5 pounds at B. Now, if A C be supposed the handle of a common hammer, B the drawing part, and X the point resting on the bench, &c., then five times less force would be required to draw a nail in this way, than would be necessary to effect the same by means of an upright pull of a pair of pincers.

LETTER VIII.

The Wheel and Axis described, and its Principle explained—Its varieties and uses illustrated—Wheel and Pinion—The different kinds of Cranes described—The Principle of the Pulley explained.

HAVING considered at large the different kinds of levers, I shall proceed with the other mechanical powers, beginning with the wheel and axis, which, in many books, is called the "axis in peritrochio," and which gains power in proportion as the circumference of the wheel is greater than the circumference of the axis: see fig. 33-5. The wheel and axis may be referred to the principle of the lever, as is evident by fig. 33, in which A B represents the wheel, C its axis, and if the circumference of the wheel be twice as large as that of the axis, then a single pound at P will balance 2 pounds at W. For the circumferences of wheels bear the same proportion to one another that the radii have. As a lever, C, may be considered the fulcrum, or centre of motion, and B C, the radius of the wheel, is the longer arm of the lever; A C the radius of the axis, is the shorter arm, and then, by what you have seen, there will be an equilibrium when the power P, multiplied into B C, is equal to the weight W, multiplied into A C. The advantage gained is lost in the time, or in the space moved through; for while P descends through two feet or inches, W will ascend only one foot or one inch. The wheel may bear

almost any proportion compared with the axis, provided the latter is not made too small to sustain the weight, nor the former too large to be manageable; and power is gained either by diminishing the diameter of the axis, or increasing that of the wheel. In most instances, instead of a large wheel A B, fig. 34, a handle or winch is used at Q, which, by its circular motion, answers the purpose of a wheel. This is the case in winding up a jack, and in raising water from a deep well. Sometimes long spokes are used, as S S, in fig. 35, where one, two, or more men may apply their force at the points to turn the axis.

Cranes for raising goods out of, or into ships, warehouses, &c., are formed on the principle of the wheel and axis, but, as you may not immediately see the mode of estimating the power, I will go through two or three examples, which relate to the crane, capstan, &c.

The large circular crane, in which one, or two, or more men walk, is rather an unwieldy machine, but is still used at many wharfs, where much power is not required; fig. 37, is a section of it, and the position of the figure at *m* shews to what part the man, or men, can climb, so that the line *c z*, is the long end of the lever, and *d z* the short end, and advantage is gained in proportion as *c z* is longer than *d z*, which is seldom more than two or three to one. Upon this principle you have seen at the doors of wire-workers, cages, with a bird, or a squirrel, within side, turning round the wheel by its own weight; and, if a small weight were suspended to the axis of the cage, the bird by its motion would draw it up, for, as it hops from the bottom bar

to the next, its momentum causes that to descend, and thus continues its motion.

The capstan, A B, fig. 38, has its axis *a*, beneath the surface of the ground, turning in strong fixed timbers. Handspikes are put into the holes, as *s*, and these are turned by men or horses, which, by walking round, coil the rope and raise the weight W. If each handspike be 6 times longer than the radius of the windlass, and if there be 4 of these spikes against which men act, the power gained will be $6 \times 4 = 24$, or four men will be able to raise 24 times as much weight by this machine as one man could do by his unassisted strength.

The third mechanical power is the pinion and toothed wheel.

It consists of two wheels of very unequal size, cut or notched all round into teeth; the number is immaterial provided they fit into each other, to do which the teeth in the small wheel must be to those in the great one as the diameter of the former to that of the latter.

The small wheel is generally called a pinion, and its teeth, leaves.

To calculate the advantage gained by the wheel and pinion, divide the number of the teeth in the wheel by the number of leaves in the pinion, the quotient will be the answer. For example let there be 63 teeth in the wheel, and 7 leaves in the pinion, then $\frac{63}{7} = 9$ equal to the power gained.

The wheel and pinion is applied to a great variety of purposes, sometimes for gaining power, but more frequently for gaining velocity. The crane, which I will

describe presently, is an instance of the former application. Mill and clock work afford numerous instances of the latter.

Sometimes wheels without teeth are made to act upon each other by means of strings, or straps passed round them, as in turning-lathes, mills, and planetaria. Seldom with a view of gaining power, as that would be impracticable on account of the liability of the rope to slip, though frequently for the purpose of obtaining a very rapid or exceeding slow motion.

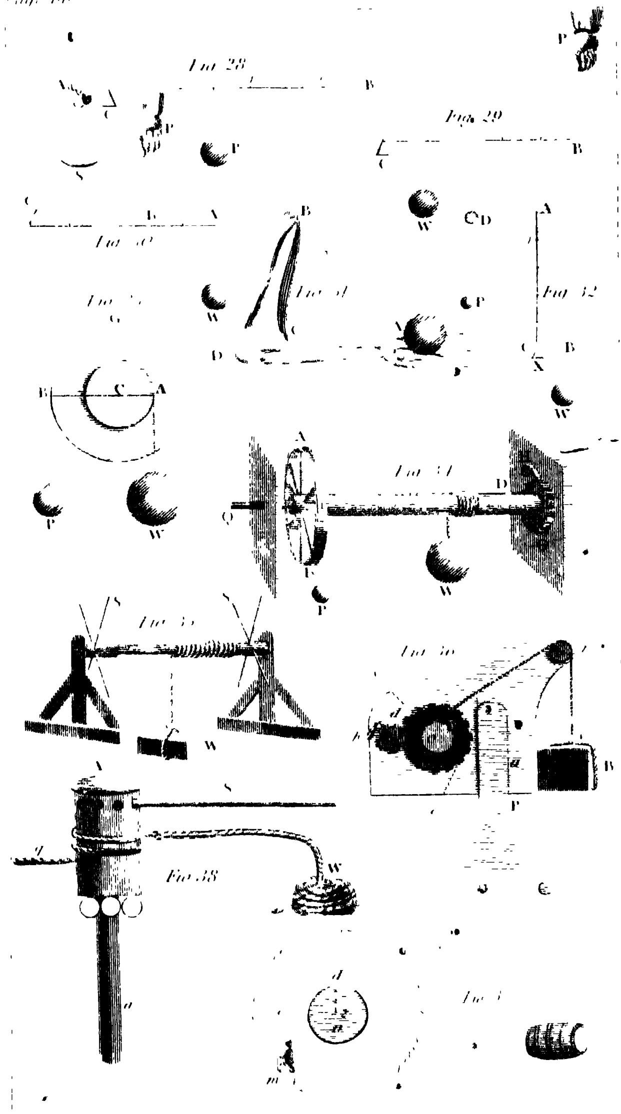
The crane just now alluded to is represented in fig. 36, plate III. It is much used at the water side, and is moveable on a post P, fixed in the ground. The bale of goods B, is caught by the hook *s*, the rope passes over the pulley *r*, and is coiled round the axis *o*, as the wheel is turned. This large wheel is turned round by means of the teeth catching into the teeth of the pinion *d*, and the handle *h*. If the handle *h*, be three times as long as the radius of the pinion, then, by the principle of the lever, it will gain power as three to one. But the radius of the wheel is twice as large as that of the axis round which the rope is coiled, which gives another advantage of two to one. So that, by these powers combined, the advantage gained is 6 to 1, or a man would be able to raise six times as much weight, by a crane of this description, as he could with his unassisted strength. The pulley *r* serves only to change the direction of the draught, that is, by means of the pulley the weight may be raised to the height required by a person standing on the same level with it; and, as the whole is

moveable on the post P, the package may be easily drawn from, or lowered down on either side on which the vessel may happen to be placed.

The fourth mechanical power is the pulley; this is formed of wood or metal, with a groove in its circumference, which is placed in a frame of wood, and turns on its axis. The principle of the pulley may be illustrated by that of the lever. A B, fig. 39, plate IV. may be conceived to be a lever, the arms of which, A C, B C, being equal; and C is the fulcrum or centre of motion. If the weights W and P, be hung on the cord passing over the pulley, they will balance one another, and the fulcrum will sustain them both. Here then no advantage is gained, but, as we have seen, it is useful in changing the direction of a draught, and is much used in drawing up small weights to the tops of high buildings, it being easier for a man to raise such burdens by means of a single pulley, than to carry them up a high ladder.

The pulley becomes a mechanical power when it is moveable, as fig. 40, or when it is combined into a system, as fig. 41.

In the pulley C D B, fig. 40, C may be regarded as the fulcrum, and, by the principle of the lever, C A is the shorter arm, and C B the longer; and C B being double C A, a power, P, of 1, acting at the end of the longer lever, will sustain a weight, W, of 2, acting at A. The subject may be considered in a different way: the whole weight W, is sustained by the cord E D P, one half of which is sustained by the hook E, consequently the power



has only the other half to sustain, or, generally, any given power at P will keep in equilibrio double weight at W. You will observe the velocity of the power P, will be double that of the weight W, for in raising the latter one inch, or foot, both sides of the cord must be shortened one inch, or one foot; of course the hand, P, must move through two inches, or two feet. Hence, and with a view of figure 41, you will easily perceive that, in a system of pulleys, the power gained must be estimated by doubling the number of pulleys in the lower block. So that when the fixed block X, contains two pulleys which merely turn on their axes, and the lower block Y, contains also two, which not only turn on their axes, but also rise with the weight, the advantage gained is as 4 : 1.

The modes of arranging pullies are very various, the following are among the most common: fig. 42 is an arrangement of pullies in ship's tackles, with a force of six to one. Fig. 43 is an arrangement of pullies in a vertical line, with a force of six to one. And fig. 44 is a system of pullies, fixed on one axis in each block, having a power of 10 to 1: this last was invented by Mr. James White, who obtained an exclusive right of manufacturing it by letters patent.

In general the advantage gained by pullies may always be estimated from the consideration that every part of the same thread must be equally stretched; and, where there is only one thread, the weight will be equally divided among all the portions which help to support the moveable block, each of them bearing a weight equivalent to the force which is applied at the end of

the thread. In the common ships' blocks, fig. 42, the pullies are equal in magnitude, and placed side by side; they must not exceed two or three in a block, because they are apt to produce an obliquity, or twist, when the force is applied to the rope.

Considerable allowance must, in the use of pullies, be made for the friction of the cords, and of the pivots on which the pullies turn. Three things occasion much inconvenience in the use of pullies, as a mechanical power. First, the diameters of the axes bear a great proportion to their own diameters. Secondly, in working, they are apt to rub against one another, or against the side of the block. Thirdly, the chief disadvantage is the stiffness of the rope, that goes over and under them. The first two objections are mostly obviated by Mr. White's pulley, fig. 44; B is a solid block of brass, with grooves cut in it, in the proportion of 1, 3, 5, 7, &c., and A is another block of the same kind, whose grooves are in the proportion of 2, 4, 6, 8, &c., and round these grooves a cord is passed, by which means they answer the purpose of so many distinct pulleys. But Mr. White's pulley, though ingenious in theory, is not found to answer in practice. The exact proportion between the grooves, however nicely adjusted by the maker, is soon destroyed by unequal wear, which occasions the rope to drag. This can never happen in the common system, where every pulley turns on its own axis.

LETTER IX.

Of the inclined Plane, its Principle and Uses—What Instruments referred to it—Of the Wedge, its Principle and Uses—Of the Screw, its Principle and Uses.

THE inclined plane is the fifth mechanical power, of which fig. 45 is a representation, and the advantage gained is estimated by considering the length of the plane B C, compared with its height A C. If B C be 3, and A C = 1, then the advantage is as three to one; in other words, a cylinder E, of stone, &c. might be drawn up the plane with one third part of the strength that must be exerted in lifting it up at the end. Here again we revert to the general axiom, that what is gained in power is lost in time, or in the space passed over. For the length of the plane is three times as great as its perpendicular height.

The inclined plane is chiefly used for raising heavy weights to small heights; thus we frequently see a plank, or planks, laid down in a sloping direction, which act as an inclined plane, and upon this casks may be rolled, or wheel-barrows driven, which are heavily loaded.

The force with which a body descends upon an inclined plane, is to the force by which it would descend perpendicularly in free space, as the height of the plane is to its length.

EXPERIMENT. Let two marbles drop out of your

hand at the same instant, the one may roll down an inclined plane, and the other fall perpendicularly in free space; the times of descent, if the plane be long, will be very manifest. This subject may be thus illustrated:

1. If the plane A B, fig. 46, be parallel to the horizon, a marble, or a cylindrical body, C, will be at rest on any part of it where it is laid. But if the plane be placed perpendicularly, as A B, fig. 47, the cylinder will descend with its whole weight, and would require a power equal to its weight to keep it from descending. And if the plane be inclined to the horizon, as A D, fig. 48, and be four times the length of the perpendicular D B, the cylinder, or marble, will be supported by a power equal to a fourth part of its weight.

The velocity with which a body falls must be estimated by the force acting upon it. Therefore, if an inclined plane be 32 feet long, and its perpendicular height be 16 feet, a marble, or cylinder, will, by the force of gravity, fall through the 16 feet in one second; but in descending along the plane, it will occupy 2 seconds. Again, if the plane were 64 feet in perpendicular height, and three times 64, or 192 feet, in length; then in free space it would, by the action of gravity, fall in 2 seconds, but on the plane it would be 3 times 2, or 6 seconds.

Hence, as I have before observed, the advantage gained by this mechanical power is in proportion as the length of the plane exceeds the perpendicular height: thus, if the plane be 12 feet long, and the height be 4 feet, a cask weighing 3 hundred weight would be balanced upon it by 1 hundred weight, because the plane

is three times the length of the perpendicular height to which the weight is to be raised.

To the inclined plane may be reduced hatchets, chisels, and other edged tools, which are sloped only on one side.

The wedge is the next mechanical power, which is made up of the two inclined planes, joined together at their bases: thus, fig. 49, D E F and C E F are the two inclined planes, united at their bases C E F G; D C is the whole thickness of the wedge at its back A B C D, where the power is applied; D F and C F are the length of the sides. There will be an equilibrium between the power impelling the wedge downwards, and the resistance of the substance acting against its sides, when the thickness D C of the wedge is to the length of the two sides as the power is to the resistance.

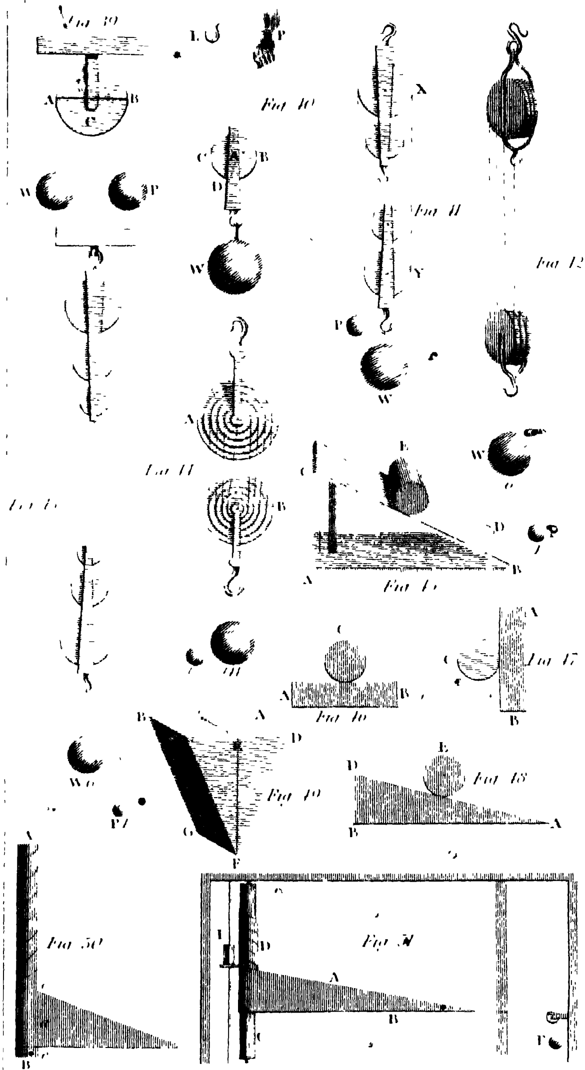
The wedge is used for cleaving wood, stone, &c., and when the wood cleaves at a distance before the wedge, the advantage is to be estimated by the proportion of the two sides of the cleft to the length of the back, or, which is the same thing, as one side of the cleft to half the length of the back.

The wedge is usually made of iron when used for splitting wood or rocks; but if it is made use of for raising great weights it is frequently made of wood. The force given to a wedge of any kind is generally applied by a stroke, and not by dead pressure; for a sharp blow with a small hammer will overcome more resistance than a large weight. And a blow from a sledge hammer, used by blacksmiths, will, in cleaving wood or stone, overcome more resistance than the pressure of

several tons weight; because, as we have seen before, there is no mode of instituting a comparison between the force of momentum and of a dead weight. All instruments which slope off to an edge on both sides, such as axes and chisels, are to be referred to the principle of the wedge.

The screw is the last of the mechanical powers, which, though a simple power in itself, cannot be used without the assistance of one of the others, as a lever or winch, by which it becomes a compound engine of great power. The screw is a spiral* thread or groove cut round a cylinder; when the spiral is formed *upon* a cylinder, it is called a male screw; but when it is cut in the inner surface of a hollow cylinder, it is called a female screw If the spiral thread were unfolded it would form an inclined plane; the length of which would be to its height as the circumference of the cylinder is to the distance between the threads. You may try the thing for your self; cut a piece of writing paper in the shape of a triangle, fig. 50, and wrap it about a cylinder A B, as your round ruler, and you will find it makes a spiral, answering to the spiral part of the screw. Suppose the circumference of the rule to be three inches, and you find the distance of the threads to be half an inch from one another, then, in a screw of this kind, the power gained will be as six to one, which is evident from the principle explained in the inclined plane. The height raised is

* The thread of a screw, properly speaking, is a helix, a spiral is a curve capable of being described on a plane. (See fig. 7, miscellaneous plate II.) A helix cannot be so described; the common corkscrew is a helix.



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half an inch; but to obtain this ascent the power must move the whole circumference of the cylinder, which is three inches, or six half inches; therefore, the space passed over by the power, being 6, and that passed by the weight being only 1, the power gained is as six to one.

An instrument has been contrived to shew the equilibrium obtained in the action of the screw. A B C, fig. 51, is a thin wedge of pasteboard, or other elastic substance, the height of which is one fifth of the length, and being rolled round the cylinder D C, makes a screw, by means of which the weight E of 1 ounce, will sustain a weight F, of 5 ounces.

It is obvious then, that the smaller the distance between the threads of the screw, the greater will be the power of this machine: if, for instance, the distance between them were the $\frac{1}{3}$rd or the $\frac{1}{4}$th of an inch instead of $\frac{1}{2}$, then the power gained, where the cylinder was three inches in circumference, would be in the one case as 9 to 1, and in the other as 12 to 1, because there are 9 thirds, and 12 fourths in 3 inches.

I have told you that the screw is usually acted upon with a lever or winch; I will explain a case with the lever. If the threads on a cylinder, A B, plate V. fig. 52, be made a quarter of an inch apart, and the nut D, be turned with a lever C, 30 inches long; then the circumference of the circle, made by the power, will be, in round numbers, 180 inches,* which, divided by $\frac{1}{4}$, gives

* The diameter of the circle will be 60 inches, and this multiplied by 3.16 gives the circumference; but, to avoid decimals, I multiplied it by 3.

720* for the power gained. Several men may work at such a press; now, allowing the pull or pressure of each man, on the lever c, to be equal to 120 pounds, and four such men employed, the pressure will be $720 \times 120 \times 4 = 345600$ pound.

The screw is sometimes applied to a toothed wheel instead of a pinion, it is then called a perpetual, or endless screw, from its constantly moving in one direction.

Since every turn of the screw throws off a tooth, the power gained by this combination is evidently equal to the number of teeth in the wheel, independent of any advantage derived from the winch. Thus in figure 11 of miscellaneous plate I., let a, the winch be 20 inches long; b, the screw, 2 inches in diameter; c, the wheel with 30 teeth; and d, the cylinder, half the diameter of the wheel: then the power gained will be,

From the proportion of the winch to that of the screw, 20 : 1 20
From that of the screw to the wheel, 1 : 30 30
From that of the wheel to the cylinder, 2 : 1 . . . 2

These numbers multiplied together give 1200 for the whole power gained.

* To divide a whole number by a fraction, "multiply the said number by the denominator of the fraction, and divide by the numerator:" thus $180 \div \frac{1}{4} = \frac{180 \times 4}{1} = 720$.

LETTER X.

General Observations on all the Mechanical Powers—of Friction—Friction-rollers, to what applied—Explanation of a Machine to illustrate all the Mechanical Powers—the principal moving powers described and estimated.

HAVING described, in my former letters, the mechanical powers in the order in which they are usually arranged, it may be necessary to draw your attention to some farther observations on the subject:

1. Though the operations of all the mechanical powers essentially differ from one another, the principles are reducible to the lever, or the inclined plane. The wheel and axle, and pulley, belong to the lever; and the wedge and the screw to the latter.

2. In all kinds of equilibrium that we have considered, it must be evident, with a very little reflection, that the forces, or weights, opposed to each other, are so arranged, that if they are put in motion their momenta in the direction of gravity would be equal and contrary, the velocity being as much greater as the magnitude of the weight or force is smaller. If an ounce weight, placed on a lever, at the distance of 20 inches from the fulcrum, counterpoise a weight of four ounces at the distance of 5 inches, the velocity with which the ounce would descend, if the lever were moved, would be four times as great as that with which the weight of

four ounces would ascend. A single moveable pulley ascends with half the velocity of the end of the rope which is drawn upwards, and acts with a force twice as great; a block of two shieves enables a weight to sustain another four times as great; but the velocity with which this weight ascends, is only one fourth of that with which the smaller weight must descend. When a weight rests on an inclined plane, of which the height is one third of the length, it may be retained by the action of a weight of one third its weight, drawing it up the plane by means of a thread passing over a pulley; in this case the velocity of the larger weight would be one third as great as that of the smaller.

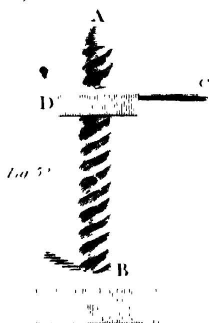
3. In all the mechanical powers, one fourth, sometimes one third, of the advantage gained must be allowed for friction; thus, if by a combination of pullies, the power gained be as 120 to 1, in order to put them in motion we must not calculate upon more than 80 to 1.

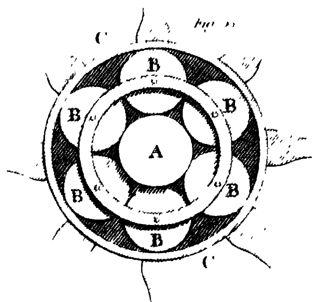
Friction is the resistance that a moving body meets with from the surface over which it passes; it is of two kinds, the rubbing by friction, and the friction by contact. The former is represented by a locked waggon wheel going down a hill, the second by the wheel touching the ground in its usual motion. The force of friction varies in proportion to the different surfaces in contact; thus, a marble passing on a smooth pavement suffers less from friction than it would from gravel, and it would be impeded in its motion still less if it were driven over ice. But the hardest and most polished bodies are not wholly free from inequalities that retard their motion when they act upon one another. The smallest

impediment from friction is, when finely polished iron is made to rub on bell-metal, but even these are said to lose about one eighth of their moving power.

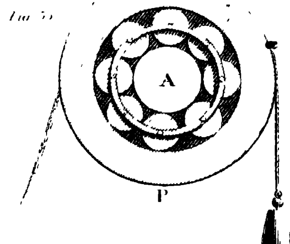
The friction between rolling bodies is much less than in those that drag; hence, in certain kinds of wheel-work, the axle is made to move on small wheels, or rollers, in the inner circumference of the nave. These are denominated friction-rollers, and are so placed together in a box, and fastened in the nave, that the axle of the carriage may rest upon them, and they turn round their own centres as the wheel continues its motion. Fig. 53, represents the section of the axle, C C the nave, and B B the friction-rollers, which turn round their own axis as the wheel revolves round the axle A of the carriage. Friction-rollers do not answer in very heavy machines, as the pressure is apt to wear the naves into notches, but in light and rapid motions they are extremely useful. Larger metal balls, on the same principle, were made use of in moving the immense block of stone from the country to the grand square of St. Petersburgh, see fig. 54. They may also be used with great effect in turning heavy bodies, as the top of a windmill, or the dome of an observatory, or such cranes as have been represented in fig. 36. Bridges over canals have been placed on this kind of rollers, or wheels, in order to be turned out of the way of boats that may be laden with light goods, and to a great height. Friction-rollers are sometimes used with pullies, as fig. 55; if the axle A be touched only by the friction-rollers, and the pulley P turn on the outside, three men are supposed to be able to do the work of five in the common way.

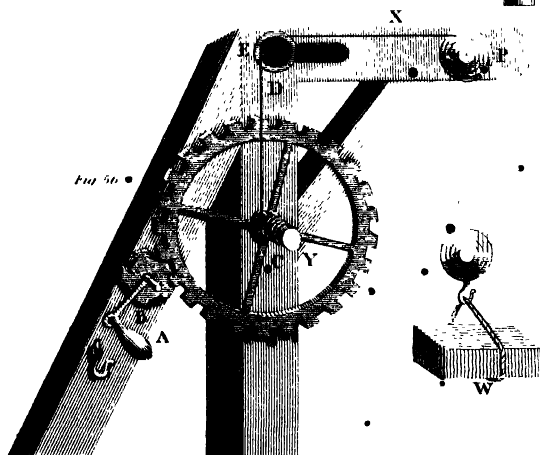
I will now give you an illustration of several of the mechanic powers, in one machine, with the figure of a common crane, taken chiefly from Mr. Adam Walker's "System of familiar philosophy." A, fig. 56, is the crank handle, which is five times as far from the centre of the pinion B as the teeth of the pinion are; hence a power of 5 is gained by the handle, according to the principle of the lever. The wheel Y is twenty times the diameter of its axis C, round which the rope is coiled, and the power gained is 20: therefore, the power gained by the wheel and axis, and handle, is equal to $5 \times 20 = 100$. The rope passes from the axis over the pulley E, which changes its direction, and carries it to the system of pullies, which is made according to Mr. White's patent, with four grooves in the lower block; this, as you know, gives a power of 8, therefore the advantage gained is 100×8 or 800, that is, a child who could exert its force at A, equal to 1 pound only, would be able to balance the weight W, of 800 pounds. But he could not put it in motion, because the friction of the parts, and the imperfection of the structure, would diminish it at least one third, or 250 pounds; and, therefore, in a crane of this kind, we must not rely upon a higher power than 4 or 500; but if a man, at ordinary work, can exert a force so as to lift 30 or 40 pounds, he would be able, by such a machine, and with as much ease to himself, to lift 400 times as much. But then he would lose in time what he gained in power, for the weight W, would ascend 800 times slower than the motion of the hand at A. Hence, in all machines whatever, what is gained in power is lost in time.











Cooper Sculp

Example. If a man can raise, with a single fixed pulley, by which he gains no advantage, a certain plank, or stone, in one minute, he will raise eight such in eight minutes, but with a tackle, having four pullies in the lower block, he will raise the eight with the same ease at once; but he will be eight times as long about it, because his hand will have eight times as much space to pass over. The great advantage, then, in the mechanical powers is, that if the six planks, or stones, were in one piece, it might be raised by a tackle, though it would be impossible to move it by the unassisted strength of a single man. Another advantage is, that by machines we can give a more convenient direction to the moving power, and apply its action at a distance from the body to be moved. I will now give a brief account of the principal moving powers, and conclude this letter.

The principal moving powers are—1. The strength of animals, as that of men, horses, and oxen; and it is ascertained that a man, of ordinary strength, is reckoned capable of doing about the fifth part as much work as a good horse.

2. The force of running waters and of wind, which are advantageous movers of water-engines, pumps, mills, &c. Running water, in which the stream is pretty constant, is preferable to wind as a moving power, on account of its uniformity.

3. The force of steam, which is the most powerful of all agents at present known, and which may be applied to a thousand useful purposes, from the smallest to the most powerful engines.

4. The weight of heavy bodies. The simple weight,

as applied to clocks, jacks, and other machines, is the power which can be readily applied as a first mover, and its action, depending on gravity, is most uniform; but as it requires to be wound up, after a certain period, it is mostly used for slow movements.

5. The force of springs. The spring, under various circumstances, is a very useful moving power, but, like the weight, it requires to be wound up after a certain time, whence it is also used chiefly for slow movements. It differs, however, from the weight, in one remarkable circumstance, which is, that its action is not uniform, being strongest when most bent; but there are methods of rectifying this defect: thus, if you look into your watch, you will see that the chain is made to wind up on a conical piece of metal, which, by being larger at the bottom, assists the action of the spring when its force is weakest.

LETTER XI.

Bodies in Motion compared—Strength of Bodies investigated—Bones of Animals stronger by being hollow—Why Stalks of Corn, Quills, &c. are made hollow—Saving by the structure of hollow Masts—Larger Bodies more liable to accident than smaller—Mechanical Powers, how proportioned—Compound Machines, how examined—Powers of Wheel-work, how ascertained—Wheels and Pinions, how proportioned.

MY YOUNG FRIEND,

BEFORE we quit the subject of mechanics, I shall endeavour to shew you the application of the general principles of the science to practical purposes. You must have observed, and a reference to the several figures, already described, will make a stronger impression on your mind, that the theory of mechanics may be traced to very simple laws.

Bodies in motion may be compared either with respect to the quantities of matter that they contain, or the velocities with which they are moved. The heavier a body, the greater power will be required, either to give it motion, or to stop it when moving; and the swifter its motion, the greater its force. Its weight, multiplied into its velocity, is called the momentum; of course the momenta of moving bodies will be in proportion to their several weights and velocities of motion: if M, *m*, represent the momenta; W, *w*, the weights, or quantities of matter; and V, *v*, the velocities of two bodies; then

the general theorem will be

$$M : m :: W \times V : w \times v$$

EXAMPLE.—If $W = 20$: $w = 10$: $V = 12$ and $v = 6$, then

$$M : m :: 240 : 60, \text{ or}$$

the momentum M, of the larger body, will be four times greater than m, the momentum of the smaller. This principle extends through the whole of mechanics. When the bodies are suspended by any machine, as the lever, the wheel and axis, pulley, &c. so as to act in contrary directions to one another; and if the machine be put in motion, and the perpendicular ascent of one body multiplied into its weight, be equal to the perpendicular descent of the other, multiplied into its weight: these bodies, whatever be their weights, will in all situations balance one another; for, as the ascent of the one is performed in the same time as the descent of the other, their velocities will be as the spaces passed over, and the excess of weight in one body is compensated by the excess of velocity in the other; so that, in all cases, you may compute the power of a mechanical engine by finding how much swifter the power moves than the weight, or how much more space it passes over in the same time; for so much is the power increased by the aid of the engine. This will be obvious on an examination of the several figures, explanatory of the mechanical powers.

The properties of the lever have been applied to the investigation of the strength of bodies. When the two arms of a lever are not in a right line, as A M, and C B, (fig. 57, plate VI.) acting against one another, on the

fulcrum A C; the power P, and weight W, will be in equilibrium, when P × B C = W × A M. If, instead of one larger power P, there had been several smaller powers acting at *a*, *b*, *c*, *d*, then the common centre of gravity of them all must be found, and at this point, as at *x*, their force will be united; and if the power *x*, multiplied into *x* C, be equal to W × A M, then the weight and power will be in equilibrium.

The sum of the powers being given, it is manifest that the farther the centre of gravity *x*, is removed from the centre of motion C, the more effect will they have in balancing the weight W, or in overcoming any other kind of resistance. Hence it was inferred, by the great Galileo, that the bones of animals, containing a certain quantity of matter, are stronger for being hollow.

Suppose C B F, represent the length of the bone, containing a given quantity of matter; and the circle C H D E, a section of it perpendicular to the length, and P a power applied along the length to break it; then the strength of the longitudinal fibres, by which the bone is preserved, may be considered as united in A, the centre of gravity of the circle C H D E, which is the common centre of gravity of those forces, whether the section be a circle, or a section of a bone; but it is evident, that the distance C A, of the centre of gravity, is greater when the section is a hollow ring, than it would be if the matter of the bone were compressed into the space *c h d e*, without any cavity; of course, the power with which the parts adhere, and which act in a direction contrary to P, is greater in the same proportion.

You will now see the reason why the stalks of corn,

the feathers of fowls, &c. are hollow; for if they were of the same size as they now are, but solid, their weight would be too great for the purposes required. If the same quantity of matter now existing in them, were compressed into a solid form, their strength would be insufficient to resist the powers opposed to them.

In many cases art has, in this respect, imitated nature. I will give you an instance, in which Mr. George Smart has applied the principle in constructing hollow masts, instead of using the timber in the solid form; by this means, not half the wood is required to make a stronger mast than those in common use.

The iron columns lately erected in front of the Opera-house are another instance of a judicious application of this principle; for by being hollow, they are not only more elegant in appearance, but much stronger than the same quantity of solid metal would have been.

It may be observed, that in similar bodies, whether in mere machines, or in the animal structure, the greater are more liable to accidents than the lesser, and have a less relative strength; that is, the strength does not in- in the proportion of their magnitudes. A large is more likely to break in its fall than one half or a third the size. A man, as experience every day proves, is in much greater danger from accidents of this sort than a child; for it is easily demonstrated, that the force which tends to break bodies, or to render them liable to dangerous accidents, increases in a greater proportion than the force which tends to keep them entire.

EXAMPLE. Suppose A B D E, and F G H K, (fig. 58), to be two beams fixed in a wall, by the ends A R E,

and F S K, the one is double the length and double the thickness of the other. But as all solids are to one another as the cubes of their sides, there will be eight times as much matter in the large beam as there is in the smaller one, and their weights may be supposed to be accumulated in the centres of gravity over the points x and z; but x is at double the distance from the wall that z is, and therefore the stress upon the ends resting in the wall, or the power tending to break them, will be $8 \times 2 = 16$ times greater in the large beam than in the small one; that is, 8 times on account of the weight, and twice by the centre of gravity of the large beam being at double the distance of that of the small one.

But the forces which tend to keep the beams entire, are in proportion to the circular sections A R E and F S K, that is, as 4 to 1, or the larger beam will be four times less liable to break than the small one; divide the 16 by 4, and still there is a proportion of 4 to 1 against the strength of the larger beam.

Hence you will easily infer, that beams, or any other bodies, may be constructed so large as to break by their own weight; and it is observed, that machines which succeed well in models, may, when executed on a large scale, fall to pieces by their own gravity.

In the construction of machines, we must consider what weight every part is to bear, and proportion the strength accordingly. In levers the strongest part must be made where the strain is greatest: thus in levers of the first kind, they must be strongest at the fulcrum; in those of the second kind, the greatest strength must be

where the weight acts upon them; and in the third, at the power.

The axis of wheels and pullies, and the teeth of wheels, must likewise be made in proportion to the work required to be done; and the excellence of all kinds of machinery is to be estimated by the proportions being properly adapted to the work to be performed.

To examine a compound machine, you will find the best method is to go to the centre of motion, and trace the parts onward till you arrive at the weight to be raised, or the power to be overcome: thus, if you wish to know how the weight W, (fig. 56, plate V.) is raised, you would go to the winch B, which turns the small wheel, and this turns the larger one; this again in its revolution winds the rope on its axis, which you may trace over all the pullies to the weight.

If you would discover the mechanical power of any engine, it will be sufficient to ascertain the spaces described by the *power* and the *weight*; for if the power passes over 6, or 8, or 12 times the space of the weight, then the power gained will be equal to 6, or 8, or 12.

Where it can be conveniently done, the compound machine may be divided, in your mind, into the simple ones of which it is composed; then call the power 1, and find the forces, in numbers, which the first simple machine exercises upon the second; then again, between the second and third, the third and fourth, and so on: multiply these numbers together, and the product will be the force of the machine, supposing the first power one.—(To refer again to fig. 56.)

Suppose the winch to be twice as long as the radius of the wheel B, then the power gained is as . . 2
If there are five teeth in the wheel B, and 30 in the wheel Y, then the little wheel will go round 6 times while the large one revolves once, and the power gained is as 6
If the axis be 20 times less than the wheel, the power gained is as 20
By the single pulley D, no advantage is gained; but in the pulley P, the power gained is as double the number of strings, that is, as 8

$2 \times 6 \times 20 \times 8 = 1920$ equal the power gained, or an exertion of one pound or hundred weight, at the hand A, will balance 1920 lb. or cwt. at W.

Again, if you would calculate the power gained in wheel-work, take the product of the number of teeth, in all the wheels that drive others, for the power; and the product of the teeth, in all the wheels moved by them, for the weight; and divide the one by the other, for the power gained. Or in wheel-work, there are either two wheels fixed on the same axis, or one wheel and pinion, as Y and B, (fig. 56); or a barrel that supplies the place of a wheel; that wheel which is acted upon as Y, is called the leader; and the other, which gives motion as B, is called the follower; then take the product of the number of teeth in all the leaders for the weight, and the product of those in all the followers for the power; divide by one another, and the quotient is the power gained.

In all cases, the number of turns of the wheel, multiplied into the number of teeth, is equal to the number

of turns of the pinion into its number of teeth; so that the number of turns in the wheel and pinions will be reciprocally in proportion to their number of teeth.

EXAMPLE. Suppose the number of teeth in a wheel and pinion be as 120 and 10, then, for every turn of the wheel, there will be 12 of the pinion: but if the number of teeth are as 60 and 10, then for every turn of the wheel there will be only 6 of the pinion; and if the number of teeth are equal in both, they will turn with the same velocity, and each turn of the wheel will have a corresponding turn of the pinion.

If there be any number of wheels acting upon so many contiguous pinions, you may divide the product of the teeth in the wheels by those of the pinions, the quotient will be the number of turns of the last pinion, for one turn of the first wheel.

EXAMPLE. Suppose three pinions of 6, 9, and 12 teeth, drive wheels of 24, 36, 48 teeth, then $\frac{24\times36\times48}{6\times9\times12}=4\times4\times4=64$, will be the number of turns made by the first pinion, while the wheel goes round once.

From what has already been said, you will be prepared to deduce a rule, by which the number of wheels and pinions being given, you will get the number of teeth, to be cut on them, to make an index, as the hand of a clock or watch turn a certain number of times.

RULE 1. Find the component primes* of the given

* The component primes, or prime numbers, are those that can be only divided by unity, so as to leave no remainder; these are 2, 3, 5, 7, 11, &c. thus the primes of 210 are found by dividing by 2,

number, which are the divisors of that number, without remainders.

II. Distribute these divisors into as many separate parts or parcels as you have wheels to use; and each part or parcel multiplied together, is to be the numerator of a fraction, of which unity is the denominator.

III. Multiply the numerator and denominator of each fraction by any number that you intend for the number of teeth in the several pinions, and the fractions will shew the number of teeth in the wheels and pinions.

EXAMPLE. Suppose I were required to make the index turn 3600 times, by means of 4 wheels and 4 pinions.

The primes of 3600 are 2, 2, 2, 2, 3, 3, 5, 5; these I am to divide into 4 parcels, because there are four wheels, and as I do not mean to have the wheels of the same size, or of the same number of teeth, I distribute them thus:

2 and 2	The parts of each parcel are	4	$\frac{4}{1}$
2 and 3	to be multiplied together for	6	$\frac{6}{1}$
2 and 5	numerators of fractions, and	10	$\frac{10}{1}$
3 and 5	will stand thus:	15	$\frac{15}{1}$

Having determined that the pinions should consist of pinions of 7, 8, 6, and 5 teeth; I multiply the numera-

3, 5, and 7, which multiplied into one another, gives the original number.

2)210

3)105

5)35

7)7

1

tor and denominator of each fraction by the number, which is equal to the number of teeth in each pinion, thus

$$\frac{4}{1} \times 7 = \frac{28}{7} = \begin{cases} \text{teeth in 1st wheel.} \\ \text{teeth in 1st pinion.} \end{cases}$$

$$\frac{6}{1} \times 8 = \frac{48}{8} = \begin{cases} \text{teeth in 2d wheel.} \\ \text{teeth in 2d pinion.} \end{cases}$$

$$\frac{10}{1} \times 6 = \frac{60}{6} = \begin{cases} \text{teeth in 3d wheel.} \\ \text{teeth in 3d pinion.} \end{cases}$$

$$\frac{15}{1} \times 5 = \frac{75}{5} = \begin{cases} \text{teeth in 4th wheel.} \\ \text{teeth in 4th pinion.} \end{cases}$$

These divisors might be arranged differently, as by putting three in one wheel, and leaving one divisor only, for another wheel, as

$$\begin{array}{r} 2 \times 2 \times 5 = \frac{20}{1} \\ 2 \times 3 = \frac{6}{1} \\ 2 \times 3 = \frac{6}{1} \\ 5 = \frac{5}{1} \end{array} \left\{ \begin{array}{l} \text{Then if the pinions are to} \\ \text{consist of 12, 7, 4, and 3} \\ \text{teeth, the teeth in the} \\ \text{wheels and pinions will be} \end{array} \right\} = \left\{ \begin{array}{c} \frac{240}{12} \\ \frac{42}{7} \\ \frac{24}{4} \\ \frac{15}{3} \end{array} \right.$$

These observations will, if properly attended to, and thoroughly understood, be a proper introduction to my next letter on clock and watch work; which depends almost wholly on a combination of wheels and pinions.

LETTER XII.

Structure, Mechanism, and mode of Operation of Clocks—How Time is accurately measured by a Pendulum—Dial-work of a Clock explained—Striking Train explained—Structure and Mechanism of Watches explained—Other Instruments to point out the Divisions of time—Of time and its divisions.

You will now be able very readily to comprehend the structure of clocks and watches; the drawing, fig. 59, which accompanies this, is a representation of the inside of a clock, seen side-ways, or such a view as you will get by opening one of the side doors of a common eight-day clock. The frame-work T T T T, is usually made of brass, and intended to hold the parts together. The weight C W, gives motion to the wheels, &c., for the cord to which it is attached, is fastened by the other end to the barrel C, at *x*, therefore, in endeavouring to descend, it turns the barrel C, to which is attached the wheel D; this wheel turns the pinion *d*, and also turns the wheels N and O, and, with the wheel O, the pinion *p* is turned, which turns *q*; but the wheel E gives motion to the pinion *e*, the wheel F, and the pinion *f* which pinion *f*, turns the crown, or balance wheel G H. The teeth of the balance wheel act upon the pallets I K, so that after one tooth, H, has communicated motion to the pallet K, that tooth escapes, and the opposite tooth G, acts upon the pallet I, and escapes in the same manner.

The motion of the pallets and crown wheel will be better understood by fig. 60. D C are the pallets moveable on the axis A, and connected with the pendulum A B, so as to vibrate with it; now, when the pendulum, by a vibration, comes into the position A X, the pallet C will escape its tooth, and D will act upon an opposite tooth, the pendulum returning, D escapes, and C acts upon another tooth, and so on.

By referring again to fig. 59, you will perceive at once, that when the pendulum is made to vibrate, all the wheels must partake of the motion, and then the weight W, acting upon the wheels, must continue their motion, and likewise the motion of the pendulum, till the cord is wound off from the barrel.

You will also observe that the quickness of the vibrations of the pendulum regulates the velocity of the wheel-work; for if the pendulum A B, swing seconds, each pallet will be extricated in a second of time; if it swing half seconds, each pallet will be extricated in half a second; of course, as the motion of the crown wheel, and that of all the other wheels and pinions is regulated by the time taken by the extrication of the pallets, it is regulated by the pendulum, and will be twice as swift in clocks, with half second pendulums, as it is with second pendulums. See Letter V. pages 39 and 40.

When the cord C x, upon which the weight W, is suspended, is entirely run down from off the barrel, it is wound up again by a key, that goes on the end Q, by turning it in a contrary direction to that in which the weight descends. You must, however, observe, that on

the barrel C are two wheels, a fourth part of which is represented in fig. 61; D is the wheel which turns the pinion L; and z the ratchet wheel, the teeth of which, when the barrel is turned the reverse way, removes the click C, so that the ratchet wheel z, turns in the direction K Y, while the wheel D is at rest; but as soon as the cord is wound up, the click falls in between the teeth which act upon it, and obliges the wheel D, to turn along with the barrel, and the force of the spring s, keeps the click between the teeth of the ratchet wheel.

Let us turn again to fig. 59, and examine how the divisions of time are pointed out by means of the hands. The wheel E, is made to revolve in an hour, and the pivot *c* of this wheel, passes on to *h*, on which the minute hand is fixed: this then points out the division of each hour into minutes, if the dial plate is so divided. Again, the wheel N turns the wheel O, which acts on the pinion p, which acts on q q, and this wheel q q, makes its revolution in 12 hours; on the pivot v, is fixed the hour hand, which, of course, marks out the day into hours. In looking at the front of a clock, the minute and hour hands appear to be on the same pivot, but that you know, is impossible, because one revolves twelve times faster than the other; that is, the minute hand makes its circuit in an hour, but the hour hand takes twelve hours for its revolution, and now you perceive that the minute hand turns on the pivot *h*, and this turns in the socket of *v*, which socket turns twelve times slower than the other.

I will now explain how time is so exactly measured by the pendulum, and by what means the several wheels

are made to turn in any given times, as an hour, twelve hours, and the like. We have formerly shown, (page 40), that pendulums vibrate slower or quicker, according to their lengths. Suppose, in our clock, the pendulum to vibrate half seconds, in this case there will be $60 \times 60 \times 2 = 7200$ vibrations in an hour. You will then, my friend, naturally ask how the wheel E, is made to take an hour precisely in making one revolution?

This depends on the number of teeth in the wheels and pinions, according to what I told you in my last letter.

Suppose the balance wheel G H, to consist of 30 teeth; then as each tooth acts separately on both pallets, which occasions two vibrations of the pendulum, the pendulum will vibrate 60 times while the wheel turns once, and as $\frac{7200}{60} = 120$, this balance wheel must make 120 revolutions in an hour. The pinion *f*, moves with the balance wheel G H, and turns the wheel F, but there are 6 teeth in *f*, and 60 in F; of course *f* will make 10 revolutions, while F makes but one revolution; therefore the wheel F turns ($\frac{120}{10} =$) 12 times, while the balance wheel turns 120 times, or while the pendulum swings 7200 times. With the wheel F the pinion *e* turns, which turns also the wheel E; but there are 6 teeth in *e*, and 72 in E; therefore the pinion e turns ($\frac{72}{6} =$) 12 times, while E turns once. Hence you see that E makes one revolution only, while *e* and F make 12, while the pinion *f*, and balance wheel G H, make 120, and while the pendulum makes 7200 vibrations, that is, in an hour:—in other words, the wheel E, and the index *h i*, make a revolution in one hour precisely.

We now come to the hour hand: the wheel N, is turned by the same axis *e*, as turns E, of course it makes its revolution in an hour; the wheels N and O have each 30 teeth; and being turned by the axis *c*, they both make a single revolution in an hour; with the wheel O, the pinion *p*, and wheel *q q* revolve; but the pinion has 6 teeth, and the wheel *q q* has 72 teeth, therefore the pinion *p*, revolves ($\frac{72}{6}=$) 12 times while the wheel *q q*, revolves once; in other words, the wheel *q q*, (to which is attached the hour hand *v u*), turns twelve times slower than the wheels O, N, and E; but E turns once in an hour, and therefore *q q* turns only once in 12 hours.

You will remember that the weight *w*, is not a necessary part of a clock, because small clocks, as those which stand on tables or brackets, do not admit of a weight to run down; these, then, are moved with a spring contained *in* the barrel, instead of a weight and cord to be wound *on* it.

If you now turn to fig. 62, you will see a different view of the inside of a clock. You observe two sets of wheels; the set connected with the barrel A, is that which we have already described; the other set, connected with B, is the striking part. These sets, or trains of wheels, are independent of one another, and each has its first mover, A and B; the train A A, is constantly going, to indicate the time by the hands on the dial plate: but the train B B, is only put in motion every hour, and strikes a bell to tell the hour. C is the barrel of the going part, having a catgut or cord, *x*,

wound round it, suspending the weight w, which keeps the clock going, in the way described above.

I now proceed with the mechanism connected with the striking of the clock: the first mover is the barrel B, having a click, such as has been described with regard to fig. 61. To this barrel is attached a wheel, *b*, called the count-wheel, having 78 teeth; it turns a pinion of 8 teeth, which is connected with the pin or striking-wheel *x*, of 64 teeth, acting also upon a pinion of 8 teeth, belonging to the detent or prop-wheel o, of 48 teeth; this turns a pinion of 6, on the same arbor with a thin vane of metal, called a fly, intended by its resistance to the air, to regulate the velocity of the wheels. Y is the hammer, and Z the bell.

The wheel *x*, has eight pins projecting from it; these, as they pass by the tail of the hammer *n*, raise it up; the hammer is returned violently when the pins leave its tail, by a spring, *m*, pressing on the end of a pin put through its arbor, and strikes the bell. There is another spring, *l*, which lifts the hammer of the bell the instant it has struck, that it may not stop the sound. The eighth pin in the wheel *x*, passes by the hammer 78 times in striking the 12 hours, because $1+2+3+4+5+6+7+8+9+10+11+12=78$, and as its pinion has eight leaves, each leaf of the pinion answers to a pin in the wheel *x*. As the great wheel has 78 teeth, it will turn once in 12 hours. The wheel *x*, having 64 teeth, eight of them correspond to one of the pins for the hammer; and as the pinion of the next wheel, *o*, has eight teeth, the wheel itself will turn once for each stroke of

the hammer. As *o* turns once for 6 revolutions of its pinion; and as P turns once for 8 revolutions of its pinion of 6 leaves, the fly *f*, will turn $6 \times 8 = 48$ times for one revolution of the wheel *o*, which is equal to one stroke of the hammer.

But you will naturally ask by what means is a clock made to strike at each hour the precise number of times required?

There are many contrivances for producing this effect; but I will confine myself to a description of one of the most simple.

As the parts which perform this office are concealed by the wheels to which we have just now referred, they could not be delineated in the same figure without producing confusion. I shall therefore merely indicate their situation in figures 62 and 66, and must refer you for a complete representation of them to figure 1 and 2 of miscellaneous plate. In wheel E, of fig. 59, plate VI. is fixed a pin, the use of which is to lift up the detent, α β δ, (see fig. 1 and 2, of miscellaneous plate I.) the further extremity of which, when down, locks into a notch, or rests against a pin in the detent wheel P, whilst its projection φ, falls into one of the notches in the wheel δ δ, which is affixed on the arbor of the count-wheel b.

The lifting up of the detent sets the striking train at liberty, and allows the weight or spring to put the whole in motion. The wheel E continues to move till its pin slips from under the detent, which would in consequence immediately drop down and lock the detent

wheel, were it not prevented by the projection φ, which rests on the rim of the wheel $\delta\ \delta$, and continues to do so until a pin in the pin wheel has raised the hammer, and caused it to strike one. By this time the detent wheel has made one entire revolution, the pin wheel $\frac{1}{8}$, and the wheel $\delta\ \delta$, $\frac{1}{78}$ of a revolution. By this means notch 2d in the wheel $\delta\ \delta$, is brought immediately under the projecting piece φ, of the detent, which slipping into the notch, allows the detent to fall down and lock the detent wheel. From this time the striking part remains at rest till the next hour, when the pin in wheel E coming in contact with the tail of the detent, raises it again. But the clock will now strike two; for notch 3 being $\frac{2}{78}$ from notch 2, the rim of the wheel $\delta\ \delta$, will support the detent until the pin wheel has gone through $\frac{2}{8}$ of a revolution, that is, till two pins have passed by and raised the hammer. And thus by continually increasing the spaces between the notches in the wheel $\delta\ \delta$, $\frac{1}{78}$ part of the whole circumference, the striking train is kept in motion until the requisite number of pins have passed the hammer, and caused it to strike the proper hour.

Figure 66, Mechanics, plate VI. represents a spring or table clock. A A′ is the going train, A′ the barrel containing the spring that keeps the going train in motion, V the chain, F the fusee, *g* the ratchets and click described in fig. 61, for preventing the fusee from turning without carrying the wheel E along with it. This wheel E turns the pinion C, which is fixed to and carries round the wheel *a*. The wheel *a* works into the pinion *i*, and turns both that and the wheel *b* affixed to it; *d* works

into a pivot not seen in the drawing, on the same arbor as the crown wheel *x*, and turns them both. 5 and 5 are the pallets.

B B′ is the clock work or striking part, B′ the barrel containing the spring, V the catgut or chain, F the fusee, *g* the ratchets and click, the same as in the time past. E the count wheel, L the pin wheel, *m* the detent wheel, *n* the fly wheel, *z* the fly and its pinion, I P O the detent, R the bell and S the hammer, *y* the spring for driving the hammer against the bell on its being disengaged from the action of the pin wheel.

The form of the spring, and also of the fusee, are nearly the same in a table clock as in a watch, but the necessity of making the fusee of a conical form being much more obvious in a watch than a clock, I shall defer entering into a description of them at present.

Clocks are generally found to lose in summer, and gain in winter, from the expansion of the pendulum rod by heat, and its contraction by cold. To remedy this defect astronomers are accustomed to apply to their clocks what are called compound or compensation pendulums. They differ very much in their construction, but all depend on the same principle, namely the different degree of expansibility of different metals.

The simplest and most elegant of these contrivances, is the mercurial pendulum. It consists of a steel rod, *ab*, (see fig. 6, misc. plate I.) with a bucket, *b c*, at the bottom filled with quicksilver, in the place of a bob. Now the expansion of the rod evidently lengthens the pendulum, but the quicksilver expanding more than the steel, causes the fluid to rise in the bucket, which, in

fact, is equivalent to raising the bob, or shortening the pendulum. And thus by duly adjusting the quantity of quicksilver in the bucket to the length of the rod, the expansion and contraction of the steel and mercury are made to counteract each other; and the pendulum, and consequently the clock, to preserve an uniform motion.

With this explanation of the interior of a clock, I think you will find no difficulty of understanding all its motions, but you will derive great advantage if, with the knowledge that this letter affords, you would call on your watch-maker, and request him to show you the mechanism of an eight-day clock.

I shall now give you a short account of the construction of watches, which I advise you to read, not only with the accompanying figures, but also with the work of your own watch standing open before you.

Watches, as well as clocks, are composed of wheels and pinions, with a regulator to direct the velocity of the wheels, and of a spring which communicates motion to the whole. The regulator and spring of a watch are inferior to the weight and pendulum of a clock. Instead of a pendulum, there is the balance H, (fig. 63,) which regulates the motion of a watch; and, in place of a weight, a spring, such as fig. 64, which is enclosed in the box, and A serves to give motion to the wheels and balance. Fig. 65, represents the inside of a watch after the upper plate is taken off; A is the barrel which contains the spring; one end of the chain is fixed to the barrel A, fig. 63, it is then rolled round it, and the other end is fastened to the fusee B.

When the watch is wound up, the chain, which was

upon the barrel, is on the fusee, and, of course, the elastic spring, in the barrel, is on the stretch, for the interior end of the spring is fixed to an immoveable axis A, about which the barrel revolves; the exterior end z, of the spring is fixed to the inside of the barrel, which turns upon an axis. You will, therefore, readily perceive how the spring extends itself, how its elasticity forces the barrel round, and obliges the chain, which is on the fusee, to unfold, and in its motion, to give motion also to the fusee. The motion of the fusee is communicated to the wheel C, thence to the pinion *c*, which carries the wheel D; this moves the pinion *d*, which carries the wheel E; this, again, turns the pinion *e*, which carries the wheel F, and gives motion to the pinion *f*, upon which is the balance wheel G, which gives motion to H.

It is evident that the hour hand *q*, turns twelve times slower than the minute hand *h*, because the pinion of twelve, on the spindle of the minute hand turns the wheel *s*, of 48 teeth; therefore, the motion of *s* is ($\frac{48}{12}=$) 4 times slower than the minute hand, but the pinion of *s*, of 16 teeth, turns the wheel *t*, of 48 teeth, and of course the motion *t* is ($\frac{48}{16}=$) 3 times slower than that of the pinion, or than that of the wheel *s*, and $3\times4=12$.

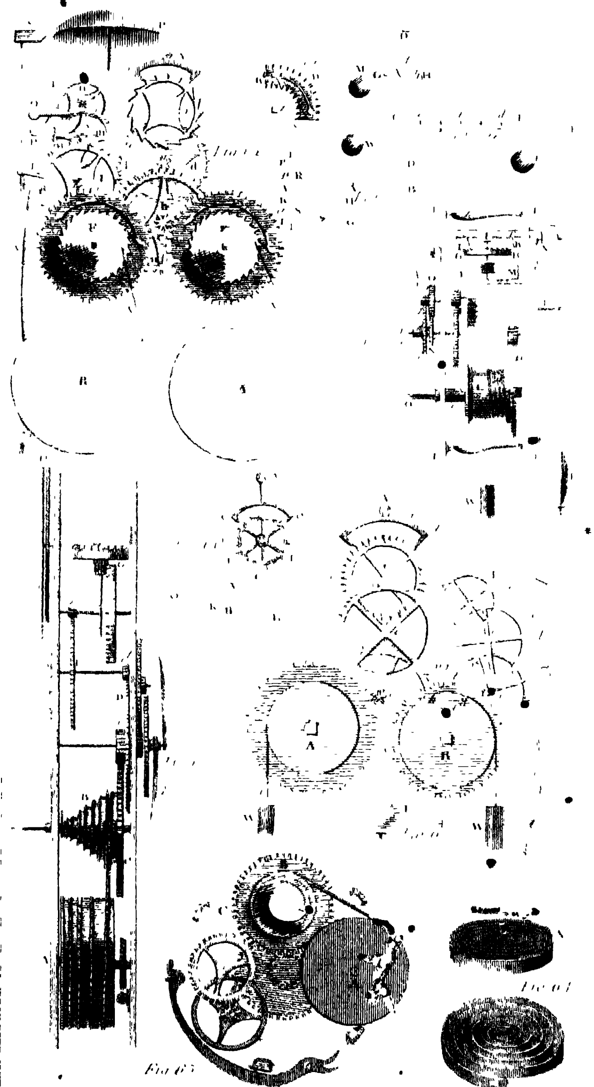
I must now shew to you how the balance is made to oscillate in a certain time, so as to regulate the going of the watch.

The pendulum of a clock has in its nature a principle of re-action, for no sooner has it swung to a certain height than it returns by the mere effect of gravity; but

the balance of a watch has no such tendency. To remedy this defect, a fine spiral spring is fixed by one end to the axis of the balance as represented in fig. 3, miscell. plate I. the other end being fastened to the framework. From the elasticity of this spring, the balance, though capable of swinging freely on either side to a sufficient distance for the pallets to clear the teeth of the balance wheel, yet has a tendency immediately to return back towards its proper point of rest between the two escapements, in which position it would finally settle after a few oscillations, were it not kept in motion by the action of the balance wheel upon the pallets.

It is upon a nice adjustment of this part of the work, and a due proportion of the strength of the main to the balance spring, that the accurate going of a watch principally depends.

The force of the balance spring may be considered as constant, but that of the main spring is obviously not so, being much stronger when first wound up than when nearly down. To compensate this inequality in the moving power, the fusee is cut into a conical form, diminishing from top to bottom. By this means the chain acts upon a shorter lever, when the spring is wound up, and upon a longer one when it is down; so as to regulate the unequal action of the main spring to a perfectly regular force upon the wheel-work. In chronometers, which are only a more accurate sort of watches, the balance instead of being an intire circle, is made with a divided rim, composed of two different metals, run or soldered together, see fig. 4, plate I. The object of this ingenious contrivance I will now explain to you.



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All metals are expanded by heat, and contracted by cold. In consequence of this property, the balance of a watch is larger in summer than in winter. By the enlargement of the balance, the rim is carried further from the centre of motion, and consequently has to pass through an arc of a larger circle than before; but the force of the spring remains the same, and therefore the balance will be longer in performing its oscillations, and the watch will go slower.

The divided rim *a b*, *a b*, as I just now observed, is composed of two metals, of very unequal expansibility, (commonly brass and steel,) soldered or run together; the most expansible metal being placed outwards.

In consequence of this arrangement of the metals, the arms *a b*, *a b*, become more bent by expansion, which carries the balls *b*, *b*, nearer to the centre, this serves to correct the expansion of the radii *c a*, *c a*, which evidently has a tendency to carry them further out; now since the principal matter of the rim lies in these balls, it is easy to see that by duly proportioning the length of the arms *a b*, *a b*, to that of the radii *a c*, *a c*, the balls may be made to preserve a precise distance from the centre under every degree of expansion, and thereby the vibrations of the balance be rendered perfectly isochronal.

Chronometers also differ from watches in another very striking particular, having what are commonly called detached escapements; but these are so various, and generally so extremely complicated in their form, as to be unintelligible without a reference to models, or to very detailed and accurate drawings. Suffice it therefore to say that the object of all these contrivances is to reduce the

impulse on the balance from a continued pressure of the teeth of the balance wheel on the pallets to a momentary *tap*, and thereby to remove, as much as possible, the errors arising from any variation in the force of the moving power, or from irregular friction, occasioned by the unequal lubricity of the oil required for greasing the machine.

Clocks and watches are of modern invention, and you will naturally ask what expedients were used for the purpose, previously to the introduction of these useful machines. You may, indeed, carry your enquiries still farther, and ask what is time; and how are the usual divisions to be accounted for?

I cannot pretend to satisfy you as to what time is; the philosophical poet asserts that

> Time, of itself, is nothing, but from thought
> Receives its rise; by labouring fancy wrought
> From things considered, whilst we think on some
> As present, some as past, or yet to come.
> No thought can think on time, that's still confest,
> But thinks on things in motion, or at rest.

Hence time is noticed by a succession of events, and it is measured by some uniform motions. By means of the common hour-glass the motion of the sand marks out the hours of the day, so long as it is attentively and accurately turned when one end of the glass is emptied. Upon a similar principle water was used to measure the lapses of time, and the machines, out of which it flowed, were called clepsydræ. After these, sun-dials were invented, which marked the times by the shadow of a style or staff, which shadow moves round with the apparent

motion of the sun, and with the real motion of the earth.

The motion of the earth is the most equable motion in nature, and the period of its revolution is divided into 24 equal parts, called hours; this is the cause of the divisions on clocks and watches being 24 in Italy, and 12 in this country, and most other places, where, for convenience, the 24 is divided into two twelves. The division of the hours into 60 minutes, and the minutes into 60 seconds, is used likewise for convenience, because the number 60 is divisible by many other numbers without a remainder.

It is agreed by all nations that the twelve o'clock hour should be when the sun is on the meridian, that is, when it is on that line that passes North and South over our heads, and hence you see the reason why clocks and watches are faster or slower in some countries than in others. Because, if you turn to your globe, you will find that Paris comes sooner to the meridian than London, and London comes sooner to it than Lisbon, but it is XII. o'clock in all countries, when those countries come to the meridian; therefore the clocks at Paris are before the clocks at London, and those at Lisbon are behind those at London.

HYDROSTATICS.

LETTER XIII.

The Sciences of Hydrostatics and Hydraulics defined and illustrated —Fluids, how defined—Fluidity, cause of—Difference between Fluids and liquids explained—Gravity of Fluids illustrated—Experiments—How lead is made to swim—Hydrostatical Paradox —Difference between Gravity and Pressure explained—Hydrostatical Bellows.

HAVING dismissed the science of mechanics, I shall proceed to hydrostatics and hydraulics, which are of great importance to the comfort and convenience of man.

Hydrostatics treat of the nature, gravity, pressure and motion of fluids in general, and of the methods of weighing solids in them.

The science of hydraulics relates particularly to the motion of water through pipes, conduits, &c. and in this sense it will appear to be of the utmost consequence to the wants of life, when we consider that on its principles depend the structure of pumps, fire-engines, pipes for conveying water from one place to another, and canals, on which much of our inland commerce depends.

In a more strict sense, the science of hydrostatics, treats of the weight and equilibrium of fluids at rest,

and that of hydraulics considers the laws of fluids in motion, that is, when the equilibrium is destroyed.

A fluid is a body whose parts yield to the smallest force impressed. There are two kinds of fluids, viz. those which are elastic, as atmospheric air, and the different gases, and those which are non-elastic, as water,* oil, mercury, &c. It is with the latter class, or rather with water belonging to this class, that we are now particularly concerned.

Philosophers have usually assumed, there being no direct proof of the fact, that the particles of fluids are round and smooth, since they are so easily moved among one another. This supposition will account for some circumstances belonging to them, with great ease. If the particles are round, there must be vacant spaces between them, in the same manner as there are vacuities between cannon balls, that are piled together; between these balls smaller shot may be placed, and between these others still smaller, or gravel, or sand may be diffused. In a similar manner, a certain quantity of particles of sugar can be taken up in water without increasing the bulk, and when the water has dissolved the sugar, salt may be dissolved in it, and yet the bulk remain the same: now admitting that the particles of water are round, this is easily accounted for.

Others suppose that the cause of fluidity is in the want of cohesion of the particles of water, oil, &c. and

* The ingenious experiments of Mr. Jacob Perkins detailed in the Philosophical Transactions for 1820, put the compressibility of water beyond all doubt, and lead to a suspicion that there is no substance in nature but what is capable of being compressed.

from this imperfect cohesion, fluids in small quantities, and under peculiar circumstances, arrange themselves in a spherical manner, and form drops.

Although air, steam, and the various gases, are fluids, as well as water, wine, oil, mercury, &c., yet to distinguish them, Dr. Young, and other philosophers, describe them in the following manner: A fluid which has no immediate tendency to expand when at liberty, is considered as a liquid: thus water, oil, and mercury, are liquids; air, steam, and the gases are fluids; the latter may be denominated elastic fluids, and the former non-elastic. With water, one of the non-elastic fluids, we are now chiefly concerned; it is subject to the same laws of gravity with solids, but on account of the less cohesive power of its parts, there are some peculiarities respecting water, which do not attach to solids. The parts of a solid are so connected, as to form a whole, and their effort is, as we have seen, concentrated in a single point, called the centre of gravity; but the parts of a fluid gravitate independently of each other, and it is on this principle, that the surface of a fluid, contained in an open vessel, is always level, or parallel to the horizon.

It was formerly supposed, that the parts of fluids did not gravitate upon each other; or that water, for instance, had no weight in water; not that it was ever doubted whether water and other fluids had weight, when considered by themselves; but it was imagined, that they had no weight, when immersed in fluids of the same kind. In proof of which, they said, that a bucket full of water, at the bottom of a well, was drawn up without difficulty till it reached the surface, and it was then

that its weight began to be felt. In opposition to this, I will describe an

EXPERIMENT.—1. Suspend from a balance, an empty phial, corked and loaded with lead, so as to sink in water; and at the other end of the balance, let the phial and lead be counterpoised with an equal weight, when it is immersed in the water. When all is in a state of equilibrio, let the phial be uncorked, and the water will rush in and fill the phial, and the equilibrium is destroyed. Now if the phial contain eight ounces of water, it will require eight ounces to be put in the other scale, to make them balance one another, which proves that the water, in the phial, lost none of its weight by being surrounded by a fluid of the same kind.

You will, perhaps, ask how we account for the ease with which the bucket is drawn up through the water.

Fluids are possessed of this property, they press equally in all directions; not only in common with solids, perpendicularly downwards, but also upwards and sideways; and therefore it is by the upward pressure of the water in the well, that the bucket so easily ascends; for the water in the bucket, being of the same weight with that in the well, a small force in addition to the upward pressure, will cause the bucket to ascend. You will, perhaps, be glad to make some experiments, to demonstrate the upward pressure of fluids.

EX. II. Take a glass tube, half an inch or more in diameter, open at both ends; stop one end with your finger, and immerse the other perpendicularly in water. While the upper end is closed, the water cannot rise but a few inches, because the air within prevents the ascent

of the water; but if the finger be removed, the air will escape, and the water will rise in the tube to the same level as it is in the vessel, being pressed upwards by the surrounding water.

Ex. III. In a bended glass tube, A B C, (plate hydrostatics, fig. 1,) I pour some sand, and when the bottom part is filled, whatever is poured in afterwards, will stand in the side of the tube in which it is poured, and not rise in the other side; because by the attraction of gravitation, all bodies have a tendency to the earth, that is, in this case, to the lowest part of the tube; but if the sand ascended in the other side of the tube, its motion would be upwards, or from the centre of the earth.

Ex. IV. Pour out the sand, and let water be put in its place, and it will be seen that this is level in both sides of the tube, proving that with respect to fluids, there is a pressure upwards at the point B, as well as downwards.

Ex. V. Take a tube, open at both ends, and ground so flat at the bottom as not to admit water; I place it in a vessel, and hold it down firmly while I pour water round it: fitting close, no water gets into the tube, but the moment I move the edge, though ever so little, the water ascends, which it must do by the upward pressure alone. The experiment would not succeed with sand, which has no upward pressure.

From this property, we learn the principle of spouting fluids; if a hole is bored in the side of an upright pipe filled with water, the fluid will spout out, which shews the lateral pressure, and this pressure is so much greater, in proportion as the hole is farther removed

from the surface; that is, a hole 3 feet below the surface of a vessel of water, will throw out in the same time, much more water, than one only a single foot below.

As fluids press equally in all directions, it follows, that the bottom of a vessel sustains the pressure of a column of the fluid, whose base is the area of the bottom of the vessel, and whose perpendicular height is equal to the depth of the fluid.

Ex. VI. In the vessel A B, (fig. 2,) the bottom C B, does not sustain a pressure equal to the whole quantity of fluid contained in the vessel, but only of a column whose base is C B, and height E G; the sides A B, C D, &c. sustain the other pressure. But in a conical vessel, F G H D, (fig. 3,) the bottom G H, sustains a pressure equal to what it would, if the vessel were as wide at the top $x\,z$, as it is at the bottom G H.

Ex. VII. The lateral pressure is shewn by the following experiment: A B, (fig. 4,) is a vessel filled with water, having two equal holes, *a b*, bored with the same tool, one at the side close to the bottom, and the other at the bottom itself: if these holes are opened at the same instant, and the water suffered to run into two glasses, it will be found, that at the end of a minute, or other portion of time, they will have discharged equal quantities of water; a proof that the water presses sideways as forcibly as it does downwards.

Hence it is clear, that fluids press equally in every possible direction, provided the perpendicular heights are equal, which may be shewn by another method.

Ex. VIII. At the bottom of a tube, two or three inches in diameter, and open at both ends, tie a piece of

bladder, and pour in some water, say six inches in height; the bladder will now be convex or bent outwards; dip it in a vessel of water, holding it still perpendicular; when immersed two, three, four, or five inches deep, the bladder will be still convex; but when it is six inches below the surface, then it becomes flat, because now the perpendicular depths being equal, the pressure upward is equal to that downwards; and the water in the tube is exactly balanced by the water in the jar; and if the tube be pressed farther down, the bladder will become concave or bent upwards, because now the water in the outer vessel being deeper than that in the tube, the upward pressure becomes greater than the downward; for the upward pressure is estimated by the perpendicular depth of the water in the outer vessel, measured from the surface to the bottom of the tube; but the pressure downwards, is estimated by the height of the water in the tube; the former, therefore, being perhaps 8 or 9 inches, and the latter only 6, is the cause of the bladder being forced upwards.

Upon the principle of the upward pressure, lead or other metal may be made to swim in water: let L B, (fig. 5), be a vessel of water; and *a b* a glass tube, open throughout: z is a string by which a flat piece of lead $\frac{1}{4}$ of an inch thick, is held fast to the bottom of the tube, to prevent the water from getting in between the lead and the glass. In this situation, if the tube is immersed in the vessel of water to about three inches depth, the string may be let go, but the lead will not fall; it will be kept adhering to it, by the upward pressure below it. The lead being about 11 times heavier than water, and

the three inches being eleven times the thickness of the lead, is the reason why that depth is fixed on. Had iron been used, the depth must have been less than 2 inches, because iron is 7 or 8 times heavier than water; and if the plate had been of gold, the depth to which it must have been plunged, would have been nearly 5 inches, because gold is 18 or 19 times heavier than water. Sometimes it is necessary to put a piece of moistened leather between the metal and glass, but to prove that the leather has no effect whatever in the success of the experiment, if the tube be drawn up an inch or two, and the string suffered to be free, it will fall off immediately, because the upward pressure is then not equal to the downward, and cannot oppose the gravity of the lead, and it falls off of course.

There is in this science, an axiom perfectly well ascertained, though denominated the hydrostatical paradox, and it is of considerable importance in hydrostatics; it is this, that a quantity of fluid, however small, may be made to counterpoise any quantity however large. We know, that in solids a lb. will only balance a lb., and a hundred-weight an equal weight; but in fluids, a pint may be made to balance a hogshead or a tun.

Ex. IX. If a wide-vessel A B, (fig. 6), containing any quantity, as a gallon or a barrel of water, and a tube C D, however small, attached to it at *x*, then pour water into them, and it will stand at the same height in both, that is the pint, or perhaps tea-cup full of water in C *x*, will balance the gallon or barrel A B *x*. See more on this subject, in Scientific Dialogues, vol. III. Conver. v.

Ex. x. Let A D B G, (fig. 7), represent a cylindrical vessel, filled with water to A, to the inside of which is fitted the cover C, so as to slide up and down, but not to admit the water to pass between its edges and the surface of the cylinder. In the cover, is cemented a small tube, F C, open throughout, communicating with the water beneath the cover C. Now, if a pound weight, x, be placed on C, the water will rise in the tube, as high as E, and if another pound be added, it will rise as high as F, and so on. Here it is evident, that as there was an equilibrium before the weights were placed on the cover, the water in the tube E C, which weighs only a few grains, is an equipoise to a pound. In other words, the column E C, produces a pressure in the water contained in the cylinder, equal to what would have been produced by the column A a d D; and as this pressure is exerted every way equally, the cover will be pressed upwards with a force equal to the weight of A a d D, for if the weight were removed, and the space *a d* D A, filled with water, it would stand no higher than E in the tube; consequently if the water contained in the space *a d* D A weighed a pound, that small quantity in E C, would sustain a pound also. The same thing might be proved of other weights and heights.

Hence it is inferred, that the pressure of fluids of the same kind, is always proportional to the area of the base, multiplied into the perpendicular height, at which the fluid stands, without any regard whatever to the form of the vessel, or the quantity of fluid contained in it.

The *pressure* of fluids, differs from the *gravity* or

weight, in this; the *weight* is according to the *quantity*, but the *pressure* is according to the *perpendicular height*.

The hydrostatic bellows is another instrument, to shew that a very few ounces of water will lift or sustain a large weight; it is made like a common bellows, only without valves at the bottom. A small tin-pipe *e o*, (fig. 8), communicates with the inside of the bellows *q p*; the upper and lower boards *x z*, are kept close together by the weight W; but they are not so very smooth but water may insinuate itself between them: and if water, perhaps half a pint only, be poured into the tube *e o*, which is very small, it will separate the bellows' boards and raise them, notwithstanding the weight, as high as z, where the water stands in the tube. If the tube were longer and smaller, the same quantity of water would raise a much larger weight. If the bellows' boards were about 12 inches in diameter, and the pipe *e o*, three feet in height, then water poured in so as to stand at *e*, would sustain on the board *x*, a weight equal to 144 pounds nearly.

By increasing the length of the tube, the pressure may be increased to almost any extent, so as to burst the strongest vessel, and it is said; that a strong cask was split by fixing in it a tin tube of twenty feet in length, and then pouring water into it, till it had filled the cask and tube to within a foot of the tube.

It may, at first be difficult to conceive how this pressure acts with so much force; but the water at *o*, is pressed with a force proportional to the altitude *e o*; this pressure is communicated horizontally in the direction *o p q*, which acts equally in all directions: the pres-

sure, therefore, downwards, upon the bottom board *z*, and upwards on the higher board *x*, is precisely the same, as if the whole space *n q p r*, were a cylinder of water.

I cannot do better than conclude this letter with a description of Mr. Bramah's hydrostatic press. This ingenious machine consists of a large cylinder A. (See fig. 10, miscell. plate), having a piston B so accurately fitted as to move freely upwards and downwards, but without suffering any water to pass. Into the bottom of this cylinder is inserted the bent tube D, having a valve at C for admitting the water into the cylinder, and hindering its return. The tube D communicates at its other extremity with the forcing pump E, by means of which the water is forced into the cylinder A. Now, the force of the water to lift the piston B will be to the power required to drive the water through the forcing pump E, as the square of the bore of the former to that of the latter; and since the two bores may be made in any proportion, it is evident there is no other limit to the power of this engine than the impracticability of constructing cylinders of immensely great, or extremely minute dimensions: for instance,

Let us suppose the cylinder to be 20 inches in bore, the pump 2 inches, and the power applied to the pump, including the advantage gained by the lever handle, to be equal to 50 lbs., then the force on the piston B will be = 5000.

For $2^2 : 20^2 :: 50 : 5000$.

LETTER XIV.

Of the specific gravities of Bodies—How discovered—Hydrostatical Balance explained—To find the specific gravity of Solids heavier than Water—Of those lighter than Water—Of Fluids, &c.—The Structure and Principles of the Hydrometer explained—Table of Specific Gravities—Air-balloons—Diving-bells.

YOU have seen, my dear sir, that lead may be made to swim in water; it would, however, naturally fall to the bottom of any vessel; but wood will of itself swim. The subject of this letter will teach you the reason of this difference, which attaches to different bodies; some of these are specifically heavier than others.

Those bodies that are heavier than water will sink in it, but those that are lighter will swim. This penny piece, thrown into water, sinks, because it is seven times heavier than an equal bulk of water; and a piece of fir, of the same size, will swim on the surface, because it is not much more than half as heavy as an equal bulk of water.

By the "specific gravities" of bodies is meant their relative weights which equal bulks of different bodies have to each other. To ascertain the specific gravities of substances in general, there must, of necessity, be a common standard, which is usually water, and by weighing bodies in this fluid their specific gravities are found.

The method of ascertaining the specific gravities of

bodies was discovered by Archimedes. He had been employed by Hiero, king of Syracuse, to investigate the texture of a golden crown, which, he suspected, had been adulterated by the workman. The philosopher laboured at the problem in vain, till, going one day into the bath, he perceived that the water rose in the bath in proportion to the bulk of his body; he instantly saw that any other substance of equal size would have raised the water just as much, though one of equal weight and of less bulk could not have produced the same effect. He immediately felt that the solution of the king's question was within his reach, and so transported was he with joy, that he leaped from the bath, and ran naked through the streets, crying out "Ευρηκα, Ευρηκα"—"I have found it out,—I have found it out!" He then got two masses, one of gold and one of silver, each equal in weight to the crown, and having filled a vessel very accurately with water, he first plunged the silver mass into it, and observed the quantity of water that flowed over; he then did the same with the gold, and found that a less quantity had passed over than before. Hence he inferred, that though of equal weight, the bulk of the silver was greater than that of the gold, and that the quantity of water displaced was, in each experiment, equal to the bulk of the metal. He next made a like trial with the crown, and found it displaced more water than the gold, and less than the silver, which led him to conclude that it was neither pure gold nor pure silver.

As a body, immersed in water, will sink, if it be heavier than its bulk of the fluid, so, if it be suspended in

it, it will lose as much of what it weighed in air as its bulk of the fluid weighs.

EXPERIMENT I. This iron weight, when balanced in the air, weighs exactly 16 ounces, by means of the hydrostatic balance, fig. 9; I suspend it in a vessel of water, as at *x*, and it weighs less, so much less as the weight of a quantity of water equal in bulk to the iron weight.

Hence all bodies of equal bulks, which would sink in fluids, lose equal weights when suspended in them, and unequal bodies lose in proportion to their bulks.

The hydrostatical balance differs but little from the common balance; the hook at the bottom of the scale *z*, is intended for the purpose of hanging the substances on, which are to be examined; the thread, attached to the hook, is made of silk or horse hair, the latter is the most proper substance as it will not imbibe moisture.

Any body, *x*, whose specific gravity is required, thus suspended at the scale *z*, is first to be counterpoised in air by weights *w*, in the opposite scale, and then immersed in water; the equilibrium will be destroyed, which must be restored by placing other weights into the scale *z*. The weight, which restores the equilibrium, will be equal to the weight of a quantity of water as large as the immersed body, and if the weight of the body in air be divided by what it loses in water, the quotient will show how much heavier that body is than its bulk of water.

EX. II. This piece of iron weighs in air 3*oz.* 10*dr.*, but when immersed in water it weighs only 3*oz.* 2*dr.*,

that is, it loses 8*dr.* of its weight in water, therefore its specific gravity is $\frac{\overset{oz.\ dr.}{3\ 10}}{8}=\frac{\overset{dr.}{58}}{8}=7.25$, or $7\frac{1}{4}$ times heavier than water.

Ex. III. Take a guinea, which, in air, weighs 129 grains, but in the situation, *x*, in a jar of water it loses of that weight $7\frac{1}{4}$ grains, and $\frac{129}{7\frac{1}{4}}=\frac{129.00}{7.25}$ gives 17.793 for its specific gravity, or it shews that the metal of a guinea is almost eighteen times heavier than water.

By this method the specific gravity of any solid substance, that will sink in water, is easily found; the rule is this, "first weigh the substance in air, then in water, and divide the weight in air by the loss in water, the quotient is the true specific gravity."

Ex. IV. A piece of flint glass, weighing 12 ounces in air, will, when suspended in water, weigh only 8 ounces, that is, it will lose 4 ounces of its weight, and $\frac{12}{4}=3$, which is the specific gravity of the glass. In other words, a portion of water of a bulk equal to the bulk of the glass, weigs 4*oz.*, but the glass itself weighs 12*oz.*, which is 3 times 4*oz.*, or the glass is three times heavier than water.

To find the specific gravity of a solid, which is lighter than water, requires a different process; it must be first made to sink in water by attaching to it a piece of lead, &c.

Ex. V. This piece of light wood weighs 330 grains, to it I attach a piece of metal weighing 240 grains, which loses by immersion in water 25 grains. In the air, the wood and metal weigh 570 grains; but in water,

they will be found to weigh only 69 grains, and 69 taken from 570, leaves 501, the difference between the weights of the substances in air and water; but the loss of the metal in water, was 25 grains; therefore the loss of the wood was $501-25=476$ and $\frac{330}{476}$ give the decimal ·7 nearly; which shews, that if the specific gravity of water is 1, then that of the wood is $\frac{7}{10}$ of 1 only, or as it is known, that a cubic foot of water weighs 1000 ounces, so a cubic foot of this wood would weigh nearly 700 ounces.

Sometimes it is necessary to find the specific gravity of fragments of precious stones, or of mercury, &c. which requires a third method. Suppose mercury to be the subject:

Ex. VI. The mercury weighs in the air 240 grains, this I suspend in the glass bucket x, which was sunk in water, and nicely balanced before. In the water, the mercury loses 17 grains, or weighs but 223 grains, and $\frac{240}{17}=14$, nearly the specific gravity of the mercury; or mercury is 14 times heavier than water.*

The specific gravity of fluids may be found by means of the hydrostatic balance thus: to the scale z suspend any heavy substance, as a lump of glass; first weigh it in air, then in water, and lastly in the fluid to be examined. Then, as the loss of weight in the fluid to the loss of weight in water, so is the specific gravity of water to the specific gravity of the fluid; or more concisely, divide the loss of weight in water by the loss of

* This subject is treated of much more at large in the third volume of the Scientific Dialogues.

weight in the fluid, the quotient will be the specific gravity of the fluid, that of water being one.

For finding the specific gravities of fluids, the instrument called an hydrometer is also used. This instrument, (fig. 10), consists of a copper ball B b, containing a few shot, or a little quicksilver, to keep it upright in a fluid, to which is soldered a flat brass wire A B, to admit of graduations; the instrument is placed in the liquor to be examined, and by the degree marked on the scale, its specific gravity is determined.

Ex. VII. To find by the hydrometer, the specific gravity of water and spirit of wine; immerse the hydrometer into vessels containing these fluids; in the water it will sink to the figure 10, and in the spirit 11.1; but it sinks deepest in the lighter fluid; therefore the specific gravity of the water to that of the spirit of wine, is as 11.1 to 10.

Hence the specific gravities of fluids, as estimated by the hydrometer, will be to each other *inversely* as the parts of the body immersed; that is, the hydrometer always sinks the deepest in the fluid of the least specific gravity. It is the same with any thing else, as well as the hydrometer.

Ex. VIII. A piece of very dry oak is nearly as heavy as water; accordingly if it be put into spirit of wine, it will sink beneath the surface; in water a small part will be above the surface, but in mercury it will scarcely sink at all.

The knowledge of the specific gravity of different bodies will explain the reason of the following experiments.

Ex. IX. Fill the bulb B, (fig. 11), with port wine, to the top of the stem x, and then fill A with water; the lighter fluid will be always upwards, and the wine being lighter than water, will ascend through the water in a sort of fine red thread, till the water and wine have changed places.

Ex. X. The small bottle A B, (fig. 12), has a very narrow neck, not more than the sixth of an inch in diameter; it is filled with red wine, and then placed at the bottom of a jar of water, a few inches deeper than the bottle is high, and the wine will immediately begin to ascend and spread itself like a cloud over the surface of the water.

Ex. XI. Let the bottle be filled with water, and then plunged with the neck downwards, in a vessel containing wine, and the wine will take place of the water.

Ex. XII. Since the lighter fluids will be always uppermost, several fluids may, with a little dexterity, be placed upon one another in the same vessel, as so many distinct layers; thus, in an upright vessel, ten or twelve inches high, and about three or four inches in diameter, I can place water, and then on that, when the water is quite at rest, I place a piece of pasteboard, and pour port-wine on it; the pasteboard may be removed and brought to the top of the wine, and on it is now to be poured oil; afterwards, in the same way, brandy, oil of turpentine, alcohol, and naphtha. You will find by the following table, that these substances are all in a regular gradation lighter than one another.

TABLE of Specific Gravities of different bodies, distilled Water being 1*.

Platina	19.50
Pure gold	19.95
Standard gold	17.48
Mercury	14.00
Lead	11.35
Standard Silver	10.40
Bismuth	9.82
Nickel	8.66
Cobalt	7.81
Copper	7.78
Steel	7.81
Bar Iron	7.78
Tin	7.30
Cast Iron	7.20
Zinc	7.19
Glass	3.00
Sulphur	2.00
Sulphuric acid	2.00
Nitric acid	1.60
Muriatic acid	1.20
Water	1.00
Oil	0.92
Brandy	0 92
Alcohol	0.82
Naphtha	0.70

The ascent of air balloons is to be accounted for on hydrostatical principles. An air-balloon is a bag of silk, or other light material, filled with inflammable air, or, as it is now called, hydrogen gas, which is several times lighter than common atmospherical air. If the balloon,

* Distilled water is found to be of the same specific gravity in all parts of the world; a cubical foot weighs 1000 ounces avoirdupoise.

with all its apparatus, be lighter than an equal bulk of common air, it will ascend precisely as light wood, or a bladder of air would ascend, when immersed in a tub of water. Balloons are constructed differently, as with hot air, which, by rarefaction, may be as light again as common air, but the principle already explained is that upon which they all act.

Lunardi was the first person, in this country, who ascended in a car, attached to the bottom of a balloon. It was in September, 1784, he rose at 2 o'clock in the afternoon, from the Artillery Ground, near Moorfields, London, by a balloon 33 feet in diameter, made of oiled silk, and painted in stripes of blue and red. He took with him a dog and a cat, and, being driven by a westerly wind, he travelled to Colliers Hill, about 5 miles beyond Ware, in Hertfordshire, a distance of 25 miles, in about $2\frac{1}{4}$ hours.

One of the last and most important exhibitions of this kind was by M. Garnerin, who ascended in the neighbourhood of Grosvenor square, to the height of 8000 feet, when he freed his car from the balloon, and descended by means of a parachute, to which it was attached: plate II. fig. 10 shows the ascent of a balloon, and fig. 11 the descent of Garnerin by means of the parachute.

You will naturally ask how is it possible that a person descending from so great a height should be preserved by a parachute from being dashed to pieces?

We have already seen that heavy bodies, from the effect of gravity, fall with a motion continually accelerated. This is strictly true in a vacuum, and would be equally

so in respect to bodies falling through a resisting medium, were the resistance uniform; but the fact is otherwise, for resistance increases as the squares of the velocities.

It has been ascertained by accurate experiments that bodies falling through the air with a velocity of 22 feet, per second, meet with a resistance equal to about one pound weight for every square foot of surface directly opposed to the medium.

Now, according to what has just been stated, that the resistance increases as the squares of the velocities; it follows, that double the velocity would give a resistance of four pounds to the square foot, and one half of the velocity a resistance of only one quarter of a pound.

The weight of Garnerin's parachute and apparatus attached to it was about $\frac{1}{4}$ of a pound for every square foot of surface directly opposed to the air in its progress downwards: so soon, therefore, as it had acquired the velocity of 11 feet per second, the resistance and weight exactly balanced each other. This, in effect, was equivalent to a cessation of gravity, and consequently the machine could only continue to move with the uniform velocity already acquired.

The diving bell likewise depends on hydrostatical principles. Take a glass tumbler and thrust it into a vessel of water, with the mouth downwards, and in a perpendicular direction; by putting a piece of cork under the glass, you will see that, however deep you thrust the tumbler, the water will only rise in it to a certain height, say $\frac{1}{2}$ an inch; the air which it contains may be so much

compressed, but it will resist the entrance of a greater quantity of fluid; and on this principle the diving-bell is constructed; see fig. 13, which is the representation of one invented by Mr. Adam Walker. The balls at bottom are made of lead, and sufficiently heavy to sink the whole apparatus; it is let down by means of the rope and pulley *x*, fastened to a beam *z*, in a ship. A bended metal tube *c b*, is attached to the outside of the machine with a stop-cock *a*, which the man within the bell may turn when he pleases: *d c* is a leathern tube and pump, so fixed in the ship as to supply the diver in the bell with plenty of fresh air.

By contrivances of this kind (though there are various sorts of diving-bells) the bottom of the sea may be explored, and lost goods recovered with as much safety almost as on land.

HYDRAULICS.

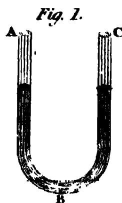
LETTER XV.

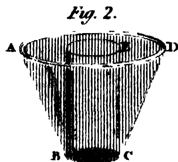
Hydraulics—Of the velocity of spouting Fluids—Of the pressure against the side of a vessel—Clepsydræ, or water-clocks—The Syphon—Periodical Springs explained—Pumps—Engines, &c.

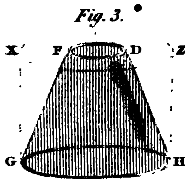
I SHALL now proceed to hydraulics, which teach us how to estimate the swiftness and the force of fluids in motion. In a former letter I showed you that an open vessel, filled with water, and with two equal holes, at the bottom, and on the side close to the bottom, would spout equal quantities of water in equal times; at first the velocity of the water is the greatest, and it decreases in strength as it continues to run. By hydraulics we point out the reason of this, and show how the velocity and quantity of the fluid is to be measured. The rule is this,

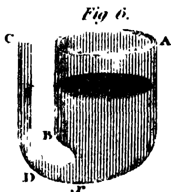
"The velocity with which water spouts out at a hole in the side or bottom of a vessel, is as the *square root* of the depth or distance of the hole below the surface of the water."

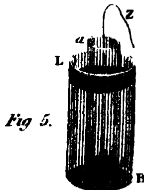
This rule is the result of the pressure of fluids against the sides of a vessel, which pressure increases against the whole side of the vessel as the *square* of the depth

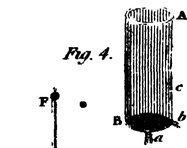


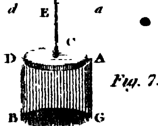


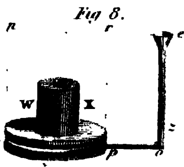


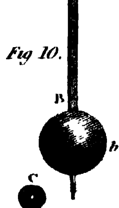


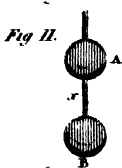




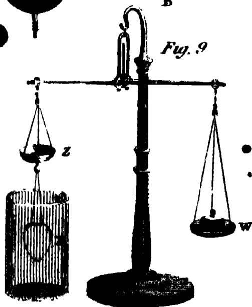


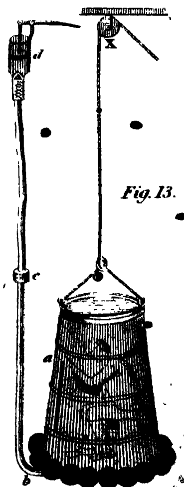












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of the vessel, which is proved by the most accurate xeperiments. Of course, to make double the quantity of a fluid run out through one hole as through another of the same size, it will require four times the pressure, and, therefore, the aperture must be made at four times the depth of the other below the surface of the water; and, for the same reason, to obtain three times the quantity, the aperture must be nine times the depth of the other.

EXPERIMENT I. Let two pipes, of equal bores, be fixed in the side of a vessel, one four times as deep below the surface as the other, and, while the pipes run, the vessel must be kept constantly full, and then it will be found, that while the upper pipe gives out one pint, the lower one will give out a quart.

EX. II. You will easily perceive that the pressure of fluids follows the same law as that which governs falling bodies; suppose *a b c d*, fig. 1, plate II. Hydrostatics, to be a cubical vessel filled with water, and the side *b c*, to be accurately divided into a number of equal parts by the lines 7, 1; 8, 2; 9, 3, &c.; now, if the pressure on the upper division of the vessel *a b* 17 be equal to one ounce or one pound, that on the second will be equal to 3 ounces or pounds, that on the third will be 5 ounces or pounds, and so on; that is, the pressure on each part of the side follows the odd numbers 1, 3, 5, 7, 9, &c., therefore, the pressures on the whole side will be as the squares of the depths; for, if the pressure on the first space be 1, and on the second 3, the pressure on the whole will be 4, the square of 2, and so of the rest.

Such, then, is the pressure of fluids against the sides of a vessel; the pressure on the bottom of a vessel, if of a cubical shape, is equal to the weight of the fluid. And as the pressure on any one side must be equal to half the pressure on the bottom, provided the sides and bottom are equal, therefore the pressure on the four sides and bottom of a cubical vessel will be equal to three times the weight of the fluid.

I will consider the pressure of fluids with regard to their motion through pipes, which is subject to the same law. We have seen, that if a cock be placed at 1, and another equal cock at 4, double the quantity will flow out at the lower one to what will proceed from the upper one. But as the quantity must be governed by the velocity, therefore the velocity with which water spouts out at a hole in the side or bottom of the vessel, is as the square root of the distance of the hole below the surface of the water. That is, the velocity of the spouting fluid at 1 being 1, it will at 4 be 2, which is the square root of 4, and at 9 it would be 3, and so on. Hence, if you had a very deep cistern, which was constantly kept full, and it had a cock a foot below the surface, and you wished to draw water from it three times faster, you must place the cock 9 feet from the top.

Hence the pressure against the side of a vessel increases in proportion to the square of the depth, but the velocity of a spouting pipe increases as the square root of the depth.

You will remember that the velocity of water running out of a vessel that empties itself, continually decreases, because, in proportion to the quantity drawn off, the

surface descends, consequently the perpendicular depths become less and less. The spaces described by the descending surface, in equal portions of time, are as the odd numbers 1, 3, 5, 7, 9, &c., taken backwards; for suppose a vessel to empty itself in 6 minutes, then, according to the law already laid down, the side must be divided into 36 spaces. The water will descend through 11 of these in the first minute; 9 in the second; 7 in the third; 5 in the fourth; 3 in the fifth, and 1 in the sixth, and these together make up the 36 parts, or the whole depth of the vessel.

On this principle clepsydræ, or water-clocks, are constructed; suppose I contrive a vessel and a pipe that shall be exactly 12 hours in emptying; I divide the side of the vessel into 144 parts, which parts must be taken as the odd numbers 1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23. The surface will descend through 23 of these in the first hour; 21 the second; 19 the third, and so on; therefore if the pipe began to flow precisely at 12 o'clock, it would be *one* when the surface had descended through 23 parts; two when it had reached 23 + 21 or 44 parts, and three o'clock when it had descended 23 + 21 + 19, or 63 parts, and so of the rest.

From the pressure of fluids upon banks of canals, rivers, reservoirs, &c., we learn the necessity there is of great strength, when the rivers or reservoirs are very deep; for if there were two reservoirs, one a yard deep, and the other 4 yards deep; the strength of the latter must, to be safe, be 16 times stronger than that of the former, because the pressure increases as the square of the depths.

I will now describe another subject, corresponding, in some degree, to what has gone before.

Let A B, fig. 2, represent a tall vessel of water, always kept full; from the centre is drawn a semicircle: three perpendicular lines are drawn, viz. *d* 2 at the centre, and *c* 1, *a* 5 at equal distances from the centre, the one above and the other below it. By taking out the plug from the centre you will see the water spouts to M, and the distance N M is double *d* 2; but from *c* and *a* it will spout in both cases to K, and N K is double *c* 1 or *a* 5.

The general rule deduced from these experiments is, that the horizontal distance to which a fluid will spout from an horizontal pipe, in any part of the side of an upright vessel, below the surface of the fluid, is equal to twice the length of a perpendicular to the side of the vessel, drawn from the mouth of the pipe to a semicircle described upon the altitude of the vessel.

If, instead of horizontal pipes, three others are fixed to point obliquely upwards at different angles, one $22\frac{1}{2}^\circ$, the second at 45°, and the third at $67\frac{1}{2}^\circ$; then the plugs being withdrawn, the stream of water will cut the curve line in those places to which the lines were drawn. That which spouts from the centre reaches the point M, as it did from the centre horizontal pipe, and the two others reach to K. Thus the pipe that is elevated at an angle of 45°, will throw water to the greatest distance, and so it is with regard to cannon; that piece will carry a ball to the greatest distance which is elevated to an angle of 45°: some allowance is, however, to be made for the resistance of the air.

Fluids, by their pressure, and by their always rising to

their first level, may easily be conveyed over hills and valleys, in bended pipes, to any height not greater than the level of the springs from whence they rise; hence the ponds at Hampstead supply houses in London with water as readily as if the head of water were ever so near. Pipes are laid down the hill, and carried to the houses in town, and other pipes carry the fluid to, perhaps, the first or second story, so that the water first falls and then rises. Where the valleys are deep, the pipes must be very strong, because the pressure is as the square of the depth.

Ex. iv. I shall now describe the principle of the syphon, pump, &c., and conclude this letter. The syphon, fig. 3, as you know, is a bended tube, the legs of which are of unequal lengths, and used to draw off water, wine, spirits, and other fluids, from vessels which cannot readily be moved from their places. If a bended tube, of rather a small bore, and whose legs are perfectly equal, be filled with water, and turned downwards, the fluid will not run off, but remain suspended therein so long as it is exactly level, but by a small inclination one leg is made in effect longer than the other, the water will flow from that, and continue to run till the vessel is emptied. When the legs are equally long, the pressure of the atmosphere being kept off from above, and acting, at the same time, equally upon both the ends of the tube, prevents the motion of the fluid, but the instant one leg is made longer than the other the balance is destroyed, the weight of the longest will preponderate, and the fluid run off, through it.

Ex. v. Take two jars and fill one with water; make use of such a syphon as that described, and you may, by

a small inclination* of the tube, empty and fill each at pleasure.

Hence syphons are made with unequal legs, as that in the figure, and to make them act, both legs are filled with the fluid you mean to draw off, and then, closing the ends with the fingers, immerse the shortest leg into the vessel, and upon withdrawing the finger from the longer leg the liquor will flow. Syphons are most commonly used in the form of fig. 4, to the longer leg of which is attached a small sucking tube *z x*; by applying the mouth to *z*, the fluid is easily drawn over the bend *y*, and when once the syphon is thus filled the liquor will flow out till the cask B is empty.

Ex. VI. A syphon may be disguised in a cup, as fig. 5. The longer leg of the syphon passes through, and is cemented into the bottom of the cup; if water be poured into the cup, so as not to stand as high as the bend of the tube, the water will remain as in any common vessel, but if it be raised over the bended part of the syphon it will run over and continue to flow till the vessel is emptied. Sometimes a syphon is concealed in the handle of a drinking cup, in such a manner as to run over when a person begins to drink, in order to deceive the unwary, who will, in vain, endeavour to stop it, after it has once begun.

Ex. VII. Upon the principle of the syphon, periodical springs are supposed to act, and may be thus explained. Let A, fig. 6, be part of a hill, within which there is a cavity B B, filled by means of water draining through the pores of the hill; when the water rises to the level C, the vein, H C D, will be full, and the water will run

through it as a syphon, and will empty the cavity B B, when it will stop till the cavity is again filled, which may not happen, perhaps, for weeks or months.

Ex. VIII. As water rises through bended pipes to the same level as the reservoir from which it proceeds, we can easily account for fountains; for if near the bottom of a vessel A B, fig. 2, a small pipe *m*, is fastened, bending upwards, the water will spout through the pipe, and rise nearly as high as the reservoir A. The reason of its not rising to a level with A is that its motion is impeded by the friction of the pipe and by the resistance of the air.

Ex. IX. The pump is one of the most useful of domestic instruments. In comparison of those who are benefitted by a pump, few, probably, understand its structure and manner of operation, but, I hope, by means of the annexed figures, you will comprehend the subject without difficulty. Fig. 7, *a* represents a ring of wood or metal, with leather fastened round it, to fit the cylinder A, very close. Over the hole is a lid *s*, covered with leather, part of which serves for a hinge; by this it rises and falls. It is called a valve, and, as it opens only upward, it will not admit of any fluid back again; the same may be said of the lower valve *v*.

The pump is supposed to stand in a well of water W; *h* is the handle by which the rod *r*, and valve *s*, are moved up and down in the barrel. When the rod *r* is forced down, the valve *s* opens and admits the air in the barrel to get above it, but, in rising, the valve is fast, and no air can repass: underneath, then, is a partial vacuum, and the pressure of the water will open the valve *v*, and

come into the barrel A; now when the handle is worked up and down two or three times the water will get above the valve *s*, and, when drawn up, will flow out of the pipe.

This kind of pump was formerly called the sucking pump, because its operation was supposed to depend on a principle of suction, an opinion that has been long since exploded. It is the pressure of the air which causes the water to rise and follow the piston as it is drawn up, and since a column of water 33 feet high, is of equal weight with a column of the air from the earth to the top of the atmosphere, therefore the perpendicular height of the piston from the surface of the water must be always less than 33 feet, or the water will never get above the bucket; but when the height is less, or about 27 or 28 feet, the pressure of the atmosphere will be greater than the weight of the water in the pump, and will, therefore, raise it above the bucket, when it may be lifted to any height, if the piston-rod be made long enough, and a sufficient degree of force be employed.

Fig. 8 will show the operation of a forcing-pump, which not only raises the water into the barrel, like the common pump, but afterwards forces it up into the reservoir K K. The pipe and the barrel are the same as in the other pump, but the piston G has no valve, it is solid and heavy, and made air tight, so that no water can get above it. In the beginning of the operation the piston, or, as it is usually called, the plunger G, is close down upon the valve *a*, and by drawing it up, a vacuum is made between *a* and G, into which the water W, in the

well, rises by the pressure of the air. When the plunger is forced down again, the water cannot return by *a*, but will be forced through the pipe M, and the valve *b*, into the vessel K; and as the pipe F *i*, is fixed into the top of the vessel, and is made air-tight, no air can escape out of it after the water is higher than *i*, the edge of the pipe; but the whole quantity of air, which occupied the space F *i*, is compressed into the smaller space *h* F, and the compressing force of the air forces it through the pipe, and the more the air is condensed, the higher will the stream rise.

Engines for extinguishing fires, and garden engines, are constructed on this principle, only with two barrels, having pistons moving up and down alternately in order to produce a constant stream.

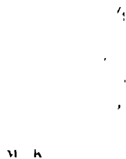
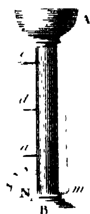
You will observe that, as in the case of fire-engines, it is not necessary for the engine to be close to the head of water from which it is supplied, but a leathern pipe may bring the water from a considerable distance to the spot where the engine is to act; so, in pumps, there are many instances where it would be inconvenient, if not impossible, to fix them perpendicularly over the well: suppose the well at A, fig. 9, and the situation of the pump at B; then the barrel B, may be sunk to a level with the water in the well, and made to communicate by means of the pipe C. The bucket will, in this situation, have as much effect as if the well were immediately under the pump, because the pressure of the air on the water in the well, will always keep the pipe A E C full.

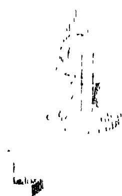
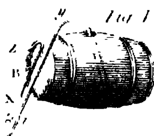
PNEUMATICS.

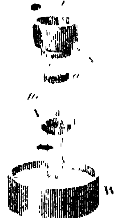
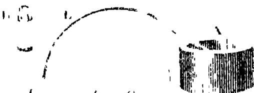
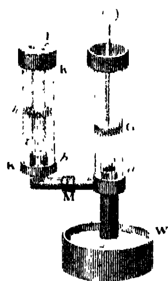
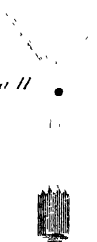
LETTER XVI.

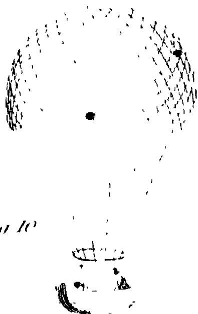
Pneumatics—Properties of Air described—Experiments to prove the Air a resisting substance—Weight of Air in a Room ascertained—Pressure of the Air demonstrated—Methods of weighing the Air—The Elasticity of the Air shewn—Of the Fountain in vacuo.

THE air which we breathe, and on which we depend every moment of our lives for existence, is as much a fluid as water, concerning which I have, in my former letters, treated at large. The air envelopes the earth, and extends to a considerable height above its surface; by this the clouds and vapours, so common in our climate, are supported, and the whole is usually denominated the atmosphere. It is known to possess gravity in common with other terrestrial subjects, and, being a fluid, it must press upon bodies in proportion to its depth, and its pressure is, like that of other fluids, in every direction. It differs, however, from them in some particulars: 1. It may be compressed into a much less space than it usually occupies. 2. It cannot be congealed into a solid substance, like water, into ice. 3. Its density decreases in proportion to its height above the surface of



Cooper sculp

the earth. 4. It is very elastic, and the force of elasticity is equal to its density.

The science of Pneumatics is usually devoted to the consideration of the mechanical properties of air, such as its pressure, weight, density, elasticity, and compressibility.

That the air is a substance capable of resistance, like other bodies, is evident from a few simple experiments.

EXPERIMENT I. A whip, or a thin stick, passed swiftly through the air, shows, by the sound, that it meets with a resisting body. By swinging the hand, edgeways, quickly up and down we obtain a complete idea of separating the parts of some resisting medium. The motion of a fan proves likewise the resistance of air.

Ex. II. An open bladder may be pressed into any shape; but if it be filled with air, and the neck tied fast, it will be as much impossible to bring the sides of the bladder together as it would if it contained a brick or a stone.

Ex. III. Upon a vessel of water place a cork, and invert over it, perpendicularly, a glass tumbler, and you may force the glass as low as you please, but the cork within the glass will never rise so high as the water without, hence it is assumed that there is some other substance within the glass, which occupies the space in which the water cannot come. Let the air escape by bringing the edge of the tumbler just above the water, and then the cork will stand at the same level within as the water does without.

Ex. IV. Open a pair of common bellows, and stop the nozzle with a cork, and no power can bring the

boards together without forcing out the cork, or bursting the leather.

The air is invisible, because it is perfectly transparent, and though, in common language, we say, "such a vessel is empty," "there is nothing in that bottle or glass," yet we do not mean to say that the air is excluded from them, but as, to the eye, the air is not visible, so, in general, we take no heed of it as a substance every where existing. Nevertheless the air weighs, at a medium, as we shall see, about 14 or 15 grains for every quart: or, to speak more accurately, it is about 800 times lighter than water. We say a room, destitute of furniture, is empty, and yet, if it be a tolerably sized apartment, the air contained in it weighs much more than would at first be credited. The room in which I sit is 18 feet long, 15 feet wide, and 10 feet high; now, as is shown in the note* below, the air contained in every room of this size, weighs 3375 ounces avoirdupoise, or 211 pounds. In buildings, or any part of them, it is impracticable, if the attempt were made, to exclude the air; but in smaller vessels, as glass receivers, the thing is done very readily by means of the air-pump, an instrument which I shall now describe.

A A, fig. 1, plate Pneumatics, are two strong brass barrels, within each of which, at the bottom, is fixed a

* The capacity of the room is found by multiplying the length, width, and height together, equal to $18 \times 15 \times 10 = 2700$ cubic feet; but we have seen that each cubic foot of water weighs 1000 ounces. Then the room filled with water, would contain 2,700,000oz., and, as air is 800 times lighter than water, we have $\frac{2,700,000}{800} = 3375$ ounces for the weight of the air in the room. See page 120.

valve, opening upwards; these valves communicate with a concealed pipe or channel that leads to K. In the barrels A A, there are two pistons, with valves opening upwards likewise; these are moved up and down by means of the racks C C, and handle B. The glass receiver L, is placed on a very smooth brass plate K, and which, by means of wet leather, or a little grease, is rendered air tight. Having shut the cock V, the pistons are worked by the winch, and the air escapes by means of the valves, which, opening upwards only, will not admit the air back again, and in a few turns of the handle the air will be so far exhausted as to fix the receiver L fast to the plate, so as to be absolutely immoveable, till the air is admitted again through the cock V.

The small receiver W *w*, contains a bottle with some quicksilver in it. The inside of the receiver W *w*, communicates with the inside of the large receiver L, and as fast as the air is exhausted in the one, it is in the other also, and in proportion to the degree of exhaustion the mercury sinks in the tube, as will be explained when we treat on the principle of the barometer.

The air, being a gravitating fluid, presses like other fluids, in every direction, upon whatever is immersed in it, and in proportion to the depths. It is known, by the barometer, that the pressure of the atmosphere is less upon a high mountain than on the plain beneath.

Ex. v. Fill a wine-glass with water to the brim, and cover it with a piece of writing paper; then place the palm of the hand over the paper, so as to hold it evenly down, and turn up the glass, after which the hand may be removed without the water running out. This effect

is produced wholly by the pressure of the external air upon the surface of the paper.

Ex. VI. Place the little glass A B, fig. 2, which is open at both ends, over the hole K, of the plate on the air-pump, and lay one hand close on the top, while, with the other, you turn the handle of the pump a few times, and you will perceive how great the pressure of the air is by the pain which it excites.

Ex. VII. You may next invert the glass, and let the wide end be uppermost, on which tie very closely a piece of wet bladder: place it as before and exhaust the air, and, after a single turn of the handle of the air-pump, the bladder will become concave by the greater pressure from without to what there is within, and after a few more turns it will burst, by the pressure, with a most violent report. A piece of thin glass may be broken in the same manner.

Ex. VIII. A, fig. 3, is a glass bubble, an inch or two in diameter, with a long neck; it is placed with the neck downwards; which neck, though open, having a narrow bore, is prevented by the pressure of the air from permitting the water to flow out. But put the jar B, in which it stands, under A on the plate of the air-pump, and exhaust the air; and when the pressure from the external air is removed, the water will flow out in a stream. Admit the air again, by turning the cock V, and the pressure which it occasions will force the water instantly into the bubble. Still you will perceive a small bubble of air at the top, this is owing to the imperfect exhaustion of the air; and that bubble of air, small as it appears, is what, by its elasticity, forced out the water, when the

external pressure was removed; and what, in its expanded state, filled the whole glass ball.

Many of the experiments belonging to this subject were formerly supposed to be performed by the principle of suction. But that which has just now been described cannot be accounted for but by pressure. The following is, however, still more conclusive:

Ex. IX. On the plate of the air-pump, and at a little distance from the hole K, place the small glass receiver *x*, fig. 4, (to prevent the air from getting under it, a little oil or water should be put round the external edges,) cover it with a larger receiver, A B, and exhaust the air from the latter, and it will find its way out of the small one likewise. When the large one is immoveable by the pressure of the air, the other will be loose, as may be known by shaking the pump; now if suction had been the cause that fastened down the one, it must have fastened the other also. Turn the cock V quickly; the air, by being admitted, suddenly loosens the large receiver, and renders the little one absolutely immoveable. Hence you must infer that the air being admitted into the receiver becomes a balance for the external pressure, and sets the large glass free; but the water round the edge of the smaller one prevents the air from getting underneath it, while, by its pressure externally, it fixes the glass down most firmly.

By this principle of pressure many facts are explained very readily; thus you have seen boys draw up a heavy stone, by sticking on it a round piece of moistened leather. For by pressing the wet leather on the stone, the air is completely displaced, and, therefore, there being

no internal pressure under the leather to balance that which is without, a greater power than the weight of the stone is required to separate the leather from it.

Ex. x. The hemispheres, fig. 5, consist of two brass cups made in an hemispherical form, when these are put together and the air exhausted, it will require a very great power to separate them. To make the experiment, the screw D, is to be put into the hole K, fig. 1, and the hemispheres are to be closed and the air exhausted; after which the cock is to be turned, and the whole to be unscrewed from the pump plate. Two people will now find much difficulty in separating the parts by main strength; but if they are hung up in a glass receiver and the external air taken away, they will separate of themselves.

Ex. XI. Fig. 6 is called the transferrer, and is admirably calculated to shew the effects of the air's pressure. The screw fits on to the plate of the air-pump, and, there being a channel along A D B, by means of the stopcocks G and H, the air may be taken away from both or either of the receivers I and K at pleasure. When the screw C, is fastened on to the pump plate at K, the receivers are loose, but as soon as the air is exhausted they become immoveable; turn the cock *d*, and they will remain so.* The air, by turning *d* and G, may be let into the receiver I, while the communication is cut off from K. I is now free and K fast, but if G be again turned to prevent the admission of more air into I, and H opened, then the quantity of air in I will be equally diffused between the two receivers I and K, and being only half as dense as the external air, they will both be fastened down

by the pressure from without, that within not being a balance for it.

Ex. XII. Some small square glass bottles are exhausted of air, and, during the operation, the pressure from without, when the inner and opposing pressure is taken away, will break them in a thousand pieces.

Ex. XIII. By another contrivance, mercury may, by the pressure of the air, be forced through the pores of solid wood like a shower of rain.

Ex. XIV. What is called the fountain in vacuo is effected by the pressure of the atmosphere; from the receiver H, fig. 7, the air is exhausted, and the pipe *a b*, which communicates with the inside of it, is put into a vessel of water W, the cock *x* turned, and the pressure on the surface of the water forces it up through the pipe in a beautiful fountain.

A very ingenious application of atmospheric pressure may be seen in the royal mint, where cylinders, with pistons very accurately fitted to them, are actually used in the place of springs.

Having given you, I think, a complete illustration of the pressure of the air, I come to speak of its weight, which is exhibited by the following experiment.

Ex. XV. Fig. 8 represents a Florence flask D, hanging on one side of a scale beam, and balanced by the scale and weights. D is fitted up with a screw and valve, by which it may be screwed on the air-pump plate and exhausted of its air, and it will be found that it weighs 15 or 16 grains less when exhausted than when it is full of air. Nothing can be more satisfactory than this experiment, for the moment the valve is opened, by being

lifted up with a common needle, the air rushes in with a hissing noise, and the original weight is restored.

The air is not always of the same density; sometimes the quantity contained in that small bottle will weigh ½ a grain more or less than it will at others. These changes in the atmosphere are commonly ascertained by means of the barometer, the construction and principle of which will be explained hereafter.

That the air is an highly elastic body is proved in various ways.

Ex. XVI. Take a bladder and blow it up with air, and, while full, let the mouth be accurately tied up, to prevent its escaping. If you now press it with the finger, an impression will be made upon it; but the moment the hand is removed, it will recover its former shape. Throw it on the ground, and it will rebound like any other elastic substance; this must be caused by the air and not by the bladder, because the latter has little or no disposition to elasticity.

Ex. XVII. A bladder containing a very small quantity of air, if closely tied up by the mouth, will, under the common pressure of the atmosphere, exhibit no signs of elasticity; but if it be enclosed in the receiver of an air-pump, and the external air taken away, then that in the bladder, however small the quantity, will distend and completely fill it: so great will be its elastic force, that if it be put in a box with a moveable lid, and weights placed on the lid, the elasticity of the air contained in the bladder will raise up lid and weights too.

Ex. XVIII. If a thin square glass bottle be hermetically sealed, but full of air, then put under a glass re-

ceiver, and the surrounding air taken away, the elastic force of that within will burst the bottle in a thousand pieces.

Whatever is elastic is capable of being reduced into a smaller space than it naturally occupies; hence air is very compressible.

Ex. XIX. A bended tube, A B C, fig. 9, is closed at A and open at C. It is, in the usual state, full of air; pour some quicksilver into it just to cover the bottom *a b*, the air is then in each leg of the same density, and as that in A B cannot escape, because the lighter fluid will be always uppermost, when more quicksilver is poured in at C, its pressure will condense the air in the leg A B; for the air which filled the whole of the part of the tube, is, by the weight of the quicksilver in the other part C B, pressed into the smaller space A X, which space will be diminished as the weight is increased; so that by increasing the length of the column of mercury in C *b*, the air in A *a* must be more and more condensed.

From this and other experiments it is ascertained that the elastic spring of air is always, and under all circumstances, equal to the force which compresses it; for if the spring, with which the air endeavours to expand itself, were less than the compressing force, it must yield still further; that is, in the present case, if the spring of the air in A X were less than equal to the weight of the mercury in the other leg, it would be forced into a yet smaller space; but if the spring were greater than the weight pressing upon it, it would not have yielded so much, because action and re-action are equal, and act in opposite directions.

Hence the reason is evident why the air near the earth is more dense than that above it, and why it continually decreases in density till at last it degenerates to nothing. The fact is ascertained by experiment and observation, and it has been illustrated in this way: suppose a number of packs of wool piled one upon another, the lowest will, by the weight of all the others above it, be forced into a less space than the next; that is, its parts will be brought nearer together, and it will be denser than the next, and that will be more dense than the one above it, and so on, till you come to the uppermost, which sustains no other pressure than what is occasioned by the weight of the atmosphere. The atmosphere is supposed to reach about 40 or 50 miles in height.

Ex. xx. The effects of condensed air are admirably exhibited by the artificial fountain, which is a vessel usually made of strong copper, as is represented by fig. 10. F is about half full of water, and the pipe *a b*, to which is attached a stop-cock *x*, reaches just below the surface of the water; to this pipe a syringe is adapted to force a large quantity of air into the vessel F, so that in the space above the water, ten or twenty times the quantity of air is condensed than it would naturally contain; and it cannot possibly escape by means of the syringe during the operation, because the valve only opens downwards, and the endeavour to escape shuts it the closer; nor can it get back through the tube *b a*, for that end *b* of the tube being under the water, the air to ascend through the tube must first descend below the water, which is impossible, as the lighter fluid

can never sink beneath the heavier. When a sufficient quantity of air is forced in, turn the cock *x*, take off the syringe and put on a jet of any form and shape, and you will get a corresponding kind of fountain.

Fountains of this kind, if properly placed when the sun shines, will exhibit artificial rainbows.

LETTER XVII.

Miscellaneous Experiments—Torricellian Experiment—Action of the barometer explained—Rule for judging of the Weather—Construction and uses of the Hydrometer—Rain-gauge and Thermometer—Scale of Heat.

I SHALL now describe a few miscellaneous experiments, and then refer to some important instruments connected with, and principally dependant upon the science of Pneumatics: and connected also with the comforts and conveniences of life.

EXPERIMENT I. The vanes *a* and *b*, fig. 11, are so contrived by the springs, *c*, to be set off at once; *a* is placed edgeways, and *b* with the surface of the leaves so as to meet with all the resistance of the air. In the open air the vane *a* will move round ten times as long as *b*, because it meets with little or no resistance from the air; but in an exhausted receiver they will both move much longer than either of them did in the open air; and as they now turn in an unresisting medium they will both stop together, because the only obstacle to their motion is the friction of the axis, which is the same in both.

Ex. II. Drop from your hand at the same time a guinea and a feather, or very light wafer, the guinea will reach the floor first, because the resistance of the air has much more effect upon light than upon heavy bodies, or it impedes most the motion of those bodies that have the

least momentum; but take away the air, and both will fall to the bottom at once. The flaps *a a*, fig. 12, are contrived to sustain two bodies, as a guinea and feather, and are kept in a horizontal position by means of the support *x*. When the tall receiver A B, is placed over the plate of an air-pump and exhausted of its air, by turning the screw *z*, the flaps fall into the position as represented in the figure, and, if you are very attentive to the experiment, you will find the guinea and feather at the bottom in the same instant. In this case, though the momentum of the guinea is much greater than that of the feather, yet as there is no resisting medium, and as we have seen, page 25, the effect of gravity is in proportion to the quantities of matter, they will both tend with the same velocity to the centre of the earth.

Ex. III. If the air be taken from the pores of a piece of dry wood, by placing it under the receiver of an air-pump while the air is exhausted, and then kept under the surface of mercury while the air is suddenly admitted, the fluid metal will, by the pressure of the air, be forced into the pores of the wood, as will be evident to the sight by splitting the wood.

Ex. IV. Place a shrivelled apple under the receiver of an air-pump, and exhaust the air from the receiver, and that which the fruit contains in itself will make it appear as plump and well-looking as if just taken from a tree; but the moment the air is re-admitted, it will return to its former shrivelled state.

Ex. V. If a new-laid egg, with a portion of its small end cut off, be put under the receiver of an air-pump, and the air taken away, the small bubble of air contained

in the great end will, by its elastic force, expand and drive out the contents of the egg from the shell.

Ex. vi. Beer, made pretty warm, and put under the receiver of an air-pump, will, when the air is nearly exhausted, appear to boil.

Ex. vii. The smoke of a candle will ascend in the air, but in an exhausted receiver it will fall to the bottom like any other heavy body, which shews that it generally ascends, because it is lighter than the surrounding air.

Ex. viii. The sound of a bell may be heard under a glass receiver while it is full of air, but when that is taken away there will be scarcely any sound, which proves that air is necessary to the propagation of sound.

Ex. ix. In condensed air the sound of a bell is much louder than in air of the common density.

Ex. x. Animals will not live, nor candles burn for a single instant, in an exhausted receiver.

Ex. xi. Suspend at one end of a balance a large piece of cork or dry sponge, and let it be counterpoised by a leaden weight. There is now an equilibrium between the two bodies; put them under a glass receiver and exhaust the air, when the cork or sponge will preponderate, and show itself heavier than the lead; but admit the air and the equilibrium will be restored. This fact is thus explained: the air is a fluid, and bodies lose as much of their weight in it as is equal to the weight of their bulk of the fluid in which they are immersed; the cork, being the larger body, loses more of its real weight than the lead, and therefore must be heavier, under the disadvantage of losing some of its weight,

which disadvantage being removed by exhausting the air, the bodies gravitate according to their real quantities of matter, and the cork which balanced the lead in air, shews itself to be the heavier body, or to contain a greater quantity of matter, when in vacuo. Hence the truth of the saying, that a pound of feathers is heavier than a pound of lead.

I have hitherto described our experiments upon the supposition that the air could be perfectly exhausted from vessels by means of the air-pump: this however is impossible, there must always remain a small quantity, but it is so small, after 12 or 14 turns of the handle of the pump, as to deserve little notice; for if the receiver hold a gallon or 60 grains of air it would not contain much above the 5000th * part of that quantity, or the $\frac{1}{80}$ part of a grain, after a dozen turns of the handle.

Ex. XII. If you take a glass tube closed at one end of about half an inch in diameter, and 33 or 34 inches long, fill it with mercury, and invert it in a bason of the same metal, taking care to keep your finger or thumb over the open end of the tube till it is below the surface of the mercury in the bason, you will then observe that the mercury sinks to about 4 or 5 inches, and the empty

* If each barrel of the air pump contained as much as the receiver, then one half of the air would be taken away at one turn, and of course one half of the remaining quantity at the next turn, and so on for each successive turn of the hand; so that the quantity will be diminished each turn in a geometrical ratio thus; $\frac{1}{2}$; $\frac{1}{4}$; $\frac{1}{8}$; $\frac{1}{16}$; $\frac{1}{32}$; $\frac{1}{64}$; $\frac{1}{128}$; $\frac{1}{256}$; $\frac{1}{512}$; $\frac{1}{1024}$; $\frac{1}{2048}$; $\frac{1}{4096}$, and though the barrels of the pump should not bear so large a proportion to the capacity of the receiver, yet an additional turn or two of the handle will more than compensate for the difference.

space above it is a perfect vacuum. In other words the mercury will always stand in such a tube, somewhere between 28 and 31 inches in height, according to the density of the air. Upon this principle barometers, or, as they are sometimes called, weather-glasses, are constructed. I have for many years been an attentive observer of the variations of the barometer, and have never seen the mercury so high as 31 inches, nor so low as 28 inches. To prove that this suspension of the mercury in the tube is wholly owing to the pressure of the air on the mercury in the bason, take a vessel D, fig. 13, containing some quicksilver, and a tube *g f*, 33 inches long, open at both ends, immersed in it; let them be placed under a large receiver X Z: C is a brass cover with a syringe H. Every thing is to be made secure and air tight, by means of wet leathers at the bottom and top of the receiver. Now by lifting up the handle I, a partial vacuum is made in the little tube *g f*, to which the syringe is screwed, consequently the pressure of the air on the mercury in the vessel D, forces it up to some height in the tube, as to X, just as water in a common pump follows the piston.

To shew that this is not owing to suction, you may place the apparatus over the air-pump plate, and exhaust the air from the receiver X Z; in doing which no change whatever is produced in the air of the tube, but the mercury in it will fall into the cup D; and so long as the receiver X Z is void of air, the syringe may be worked without raising in the least the mercury in the tube. This is called the Torricellian experiment, in honour of



Cooper sculp

Torricelli, a learned Italian, who invented it, and to whom we are indebted for the discovery of the weight and pressure of the air.

Ex. XIII. You now understand the principle of the barometer, the mercury of which rises and falls in exact proportion to the density of the atmosphere that presses upon the mercury in the box. A D, fig. 14, is a glass tube 32 or 33 inches long, closed at A, which is filled with very pure mercury, and inverted in the box D, containing the same metal; and to the upper part, in which the variations of the height of the mercury are visible, there is a scale, such as fig. 15, to mark those variations. As I have before said, the mercury never rises to 31 inches, nor falls so low as 28 inches, because a column of the atmosphere is never equal in weight to a column of mercury 31 inches long, and is always greater than a column of the same metal 28 inches long.

Hence as water will never follow in the piston of a pump more than 33 or 34 feet, so mercury will never follow the working of a syringe above 31 inches. In other words a column of the atmosphere which is about 45 miles high, a column of water about 32 feet high, and a column of mercury about 30 inches, are equal in weight to each other; and as the air is clear and dense the mercury rises, as it is lighter it falls. The scale A B only marks the variations to the $\frac{1}{10}$ of an inch, but by using that and the little scale $x\ z$, called a Vernier, from the inventor's name, the variations to the hundredth part of an inch are easily read off.

Although the scale varies only from 28 to 31 inches, yet it is supposed to begin from the surface of the mer-

cury in the cup D. The Vernier plate $x z$ is moveable, so that when the height of the mercury is to be taken, the index must be set to the upper surface of the column of mercury. The large scale is divided into tenths of an inch, but the length of the Vernier is eleven tenths, and divided into ten equal parts; of course each of the ten parts on the Vernier is equal to the tenth of an inch, and a tenth part of a tenth. But the tenth part of a tenth is equal to a hundredth part, for one tenth divided by ten is equal to one hundredth.* Suppose the index of the Vernier to coincide exactly with one of the divisions of the scale of variation as 29.6, then we say the height of the mercury is 29.6, but if it be, as in the figure, a little above the sixth division, we look and see what divisions on the Vernier and the other scale exactly coincide with each other, which we find is the second, and then we say the height of the mercury is 29.62.

The mercury in the barometer seldom stands steadily for any length of time, it is continually rising and falling, and by these variations we are in the habit of anticipating certain alterations in the state of the atmosphere: the following rules are supposed as accurate as our present state of knowledge will afford.

1. The rising of the mercury presages in general fair weather, and its falling bad weather, as rain, snow, wind, &c.

* To divide a fraction by any whole number is to multiply the denominator of the fraction by that number; thus $\frac{1}{10} \div 10 = \frac{1}{10 \times 10} = \frac{1}{100}$.

2. In extremely hot weather the falling of the mercury foretels thunder.

3. In the winter months the rising of the mercury presages frost, and in frosty weather, if the mercury fall from $\frac{1}{4}$ to $\frac{1}{2}$ an inch, or more, it is almost a sure sign of a thaw.

4. If bad weather happen almost immediately after the sinking of the mercury, it will not last very long.

5. In bad weather, when the mercury rises much and high, and continues to rise two or three days before the bad weather is over, then a continuance of fair weather will probably follow.

6. In fair weather, when the mercury falls for two or three, or more days before the rain comes on, then a good deal of wet may be expected, and probably high winds.

7. The unsettled motion of the mercury denotes uncertain and changeable weather.

After all, in our observations, we must not rely so much on the height of the mercury as on its motion up and down. Nor is this wholly to be depended on.

Other instruments are necessary to the meteorologist besides the barometer; as the hygrometer, rain gauge, and thermometer.

The hygrometer is an instrument for ascertaining the degree of dryness or moisture of the atmosphere. Hygrometers are of various constructions; some are made with hempen strings, which are known to shorten in moist weather, and to lengthen when the atmosphere is very dry. Others are made of the beard of the wild

out, which by twisting and untwisting in moist and dry weather moves an index attached to it: and some are made by balancing a large piece of sponge against a certain weight: in damp weather the sponge imbibes the moisture and preponderates, and the reverse in very dry weather.

The rain gauge is used to ascertain the quantity of rain that falls on each square foot of the earth's surface. A very good rain-gauge consists of a hollow cylinder, having within it a cork-ball attached to a wooden stem which passes through a small opening at the top; on this is placed a funnel. The water is collected in the funnel, which causes the cork to float, and the quantity is ascertained by the height to which the graduated stem of the float is raised. After every observation the water is drawn off by a pipe. The diameter of the funnel is exactly 12 inches, and that of the tube four inches, and as the areas of plane figures are to one another as the squares of the diameters, the area of the funnel is to the area of the tube as $12^2 : 4^2$, or as $144 : 16$ or dividing both by 16 as $9 : 1$: if then the water in the tube be raised 9 inches, the rain fallen, will, in the area of the funnel, which is the true gauge, be only one inch: the floating index with the cork shews the rise of the water in the gauge; so that if the float be raised 1 or 2 or 3 inches, the depth of rain fallen will be $\frac{1}{9}$th, $\frac{2}{9}$ths, or $\frac{3}{9}$ths.

A good common rain-gauge consists of a funnel containing at the opening an area of exactly ten square inches, which is put into a common bottle, and the weight of the rain collected in this is to be weighed, and

for every ounce 173 parts of an inch are to be allowed; thus suppose in a given time 12 ounces be collected in this gauge, then $1.73 \times 12 = 2.076$ which shews that the depth of rain fallen is equal to rather more than two inches.*

The thermometer is intended to mark the changes in the temperature of the atmosphere. It consists of mercury, oil, or alcohol, enclosed in a glass tube, which is fixed to a graduated frame. There are many kinds of thermometers, but that used in this country is called Fahrenheit's, from the inventor; it is represented in fig. 16; A is the bulb containing themercury, and A B the tube hermetically sealed, and it is so contrived as to be perfectly free from air; the mercury in the figure stands at 55°, by heat it rises, and by cold it sinks. The tube is fastened to the frame, and the scale is thus formed. Ice or snow is always of the same temperature: so also is boiling water; these then may be regarded as the standard points from which the scale proceeds.

The tube is put into pounded ice, and when it has remained in it sufficiently long to come to its lowest temperature the place of the upper edge of the mercury is marked 32°; it is then gradually introduced into boiling water, and when it will rise no higher, the altitude of the mercury is marked 212°. The space be-

* The reason of the rule is this: every gallon of pure rain water *weighs* 8lb. 5 oz. $\frac{2}{3}$ avoirdupoise, or 133.66 ounces, and contains in measure 231 inches, and $231 \div 133.66$, gives 1.73 nearly, that is, every ounce of water may be estimated at 1.73 cubic inches, but the area of the funnel is 10 square inches, and $1.73 + 10 = .173$.

tween these two marks is to be divided into 180 equal parts, and the part below 32° is likewise to be equally divided to the bottom of the scale, and if they go below 0, then the other divisions are marked —1,—2,—3, &c. Against 32° is written "freezing;"—against 55° "temperate:"—76° "summer-heat:"—98° "blood-heat:"—112° "fever-heat:"—176° "alcohol boils;" and against 212° "water boils."

In Fahrenheit's thermometer the freezing point is called 32°, and the boiling point 212°. In the centigrade or modern French scale, the freezing point is called 0°, and the boiling point 100. To reduce Fahrenheit's scale to the centigrade, subtract 32°, multiply by 5, and divide by 9. The quotient will give the degrees on the centigrade scale; for example, to reduce 55° by Fahrenheit to the centigrade, 55°—32°=23°; and $\frac{23° \times 5}{9}=\frac{115}{9}=12°\frac{7}{9}$; and, vice versa, to reduce the centigrade to Fahrenheit's scale, multiply by 9, divide by 5, and add 32° to the quotient: for example, to reduce 30° on the centigrade scale to Fahrenheit's: $\frac{30° \times 9}{5}=\frac{270}{5}=52°$ and 52 × 32°=84.

The utmost extent of the mercurial thermometer, both ways, is 600°, and 39° or 40 below 0, because in the former case mercury begins to boil, and in the latter it congeals; therefore, beyond these degrees mercury is no guide.

Mr. Wedgewood has contrived a thermometer which will measure the degrees of heat up to 32,277° of Fahrenheit's scale. It is known that all argillaceous bodies, are diminished in bulk by the application of great heat.

The diminution commences in a dull red heat, and proceeds regularly as the heat increases till the clay is transformed into a glassy substance. Wedgewood's thermometer consists of two rulers fixed on a plane, a little farther asunder at one end than at the other, leaving a space between them. Small pieces of argillaceous substances, made for the purpose, just large enough to enter at the wide end, are heated in the fire with the body whose heat is to be ascertained. The fire, according to its heat, contracts the earthy body, so that being applied to the wide end of the gauge, it will slide on towards the narrow end, more or less, according to the degree of heat to which it has been exposed.

Each degree of Wedgewood's thermometer answers to 130° of Fahrenheit, and his scale begins from 1077° of Fahrenheit, if it was possible to carry that so high.

The following abridged scale of heat will exhibit some curious facts which have been fully ascertained by accurate experimenters.

SCALE OF HEAT.

Mercury freezes at............	—40° of Fahrenheit.
A mixture of snow and salt sinks the thermometer to	0
Milk freezes at	30
Water........................	32
Heat of the human body in health, is from	92 to 97°
Water boils at................	2 2
Milk boils....................	213
Mercury boils	600
Iron heated to a red heat, visible by day	1077=0° of Wedgewood.

Brass melts	21
Swedish copper melts	27
Silver	28
Gold	32
Welding heat of iron from	120 to 132
Cast-iron melts....................	130
Extremity of Wedgewood's scale....	240

LETTER XVIII.

The Method of measuring the height of Mountains by the Barometer—Pressure sustained by Man—The Construction and Operation of the Steam Engine explained—its uses and Advantages pointed out.

HAVING in my last letter shewn the structure of the barometer, and its use in ascertaining the variations of the density of the atmosphere, I will now point out another purpose to which it has been applied, viz. the measuring the heights of mountains and other elevated places. It is found by accurate experiments that the mercury in the barometer falls $\frac{1}{10}$th of an inch for every 100 feet of perpendicular height. In ascending the Puy de Domme, a high mountain in France, the mercury fell three inches and a half, and the height of the mountain was found by exact measurement, with an instrument, to be 3204 feet. Snowden is ascertained by instruments to be 3720 feet high, and the mercury in the barometer fell in ascending it 3.8 inches. Hence the barometer will readily tell the height of any mountain, &c.; for if the mercury fall in the ascent 3, 5, 8-tenths, &c. we know we have gained 3, 5, 8 hundred feet in perpendicular height.

It may in this place be proper to lead you to the consideration of the immense pressure sustained by the human body: we have seen, that the pressure of the atmosphere on every square inch is equal to 14lb.; now,

the surface of a common-sized person's body is about 14 or 15 feet; suppose 14 feet only; in each square foot are 144 square inches, therefore the pressure upon such a surface is equal to $144 \times 14 \times 14 = 28224$lb., a weight which would instantly destroy life, were there not within us an elastic force of air which balances that which is without.

One of the most important of machines is the steam-engine, the structure of which you will easily comprehend. The boiler about half full of water, and standing over the fire is represented by A, fig. 17, B is the pipe to convey the steam from the boiler to the cylinder C, in which the piston, made air-tight, works up and down. *a* and *c* are the steam valves, by which the steam enters the cylinder; it is admitted through *a*, when it is to force the piston downwards, and through *c*, when it presses it upwards: the eduction valves are *b* and *d*; through these the steam passes from the cylinder into the condenser *e*, which is a separate vessel placed in a cistern of cold water, and which has a jet of cold water continually playing up in the inside of it. *f* is the air-pump, which extracts the air and the water from the condenser: this is worked by the great beam or lever R S, and the water taken from the condenser, and thrown into the hot-well *g*, through the pipe *n*, is pumped up again by means of the pump *y*, and carried back into the boiler by the pipe *i i*. *k* is another pump, likewise worked by the engine itself, which supplies the cistern in which the condenser is fixed, with water from the well W.

You will observe, that all the three pumps, viz. *k*,

which brings the cold water from the well to supply the condenser; E F, which throws the water from the condenser into the well *g*; and *y z*, which carries the water from the hot-well *g*, to the boiler, are all worked by the same beam R S, to which the piston rod *c* is attached.

The bent rods *a d* and *b c*, the first of which is connected with the steam valve *a*, and eduction valve *d*, and the second with the steam valve *c*, and eduction valve *b*, are attached to the piston rod of the air-pump by the projecting pieces *o* and *p*.

The motion of the whole machine is regulated by the fly-wheel X, on the axis of which is a small concentric toothed wheel H: a similar wheel I, is fastened to the rod T, and not turning on its axis, rises and falls with the motion of the great beam. The centres of the two small wheels are connected by a bar of iron, when, therefore, the beam R S raises the wheel I, it turns round the wheel H, and with it the fly-wheel X, which will make two revolutions while the wheel I goes round it once.

Suppose the piston at the top of the cylinder as it is represented in the plate, and the lower part of the cylinder filled with steam. By means of the pump-rod E E, the steam valve *a*, and the eduction valve *d*, will be opened together. There being now a communication at *d* between the cylinder and condenser, the steam is forced from the former into the latter, leaving the lower part of the cylinder empty, while the steam from the boiler entering by the valve *a*, presses upon the piston, and forces it down. As soon as the piston has arrived at the bottom, the steam valve *c*, and the eduction valve

b, are opened, while those at *a* and *d* are shut; the steam, therefore, immediately rushes through the eduction valve *b*, into the condenser, while the piston is forced up again by the steam. This will be seen more distinctly in fig. 18; *s* is the pipe which conveys the steam from the boiler; *a* and *c* are the steam valves, and *b* and *d* the eduction valves. When *a* is opened the steam rushes into the upper part of the cylinder, and forces down the piston; at the same instant *d* is opened, and the steam which was under the piston is forced through into the condenser *e*; as soon as the piston arrives at the bottom the other pair of valves are opened, viz. *b* and *c*, through the latter *c*, the steam rushes to raise the piston, and through *b* the steam, which pressed down before, is driven out into the pipe *v*, leading to the condenser; in this there is a jet of cold water constantly playing up, and thereby the steam is instantly reduced to cold water. The condenser *e*, fig. 17, would, of course, be soon full of water if it were not connected by the pipe *z*, with the pump *f*, which throws it into the hot-well *g*, and the pump *y z*, takes it from thence and conveys it, by means of the pipe *y i*, to the boiler A. You will observe, that the water in the hot-well, *g*, cannot intermix with that in the cold-well supplied by the pump W K, owing to the strong partition *v*. V. is a cistern through which the boiler A is supplied with hot water, and the apparatus connected with it you should understand.

The pipe *q* is turned up at bottom, to hinder the steam getting through, and preventing the free course of the water; for steam, being lighter than water, must rise

to the surface, and cannot sink through the bended part of the tube. *m* represents a stone suspended on a wire, shewn by the dotted line w, which is so balanced by the opposite weight w, as to admit a proper quantity of water through a valve leading to the pipe *q*. The stone is, by a principle in hydrostatics, with which you are acquainted, partly supported by the water; if then, by increasing the fire, too great an evaporation take place, and the water sink below the level *b b*, the stone must also sink, which will cause the valve to open wider, and let that from the cistern come in faster. But if the evaporation be too slow, the water will rise in the boiler, and the stone, also rising, will bring the valve closer, and admit less water; and by this simple and very beautiful contrivance, the water is always kept to an exact level in the boiler.

The pipes *t* and *u*, with the cocks, are intended to shew the height of the water in the boiler; *t* reaches very nearly to the surface of the water, when it is at its proper height; and *u* enters just below the surface. If the water be at its proper height, and the cocks *t* and *u* are open, steam will issue from the former, and water, by the pressure of the steam, from the latter. But if the water be too *high*, it will rush out at *t*, instead of steam: if too *low*, steam will issue out of *u*, instead of water.

The axis of the fly wheel x, is connected with the mill work or other machinery intended to be put into action; and, as it impels and governs the rest, its motion ought to be perfectly regular, and such as to give to every part, a convenient degree of velocity.

This effect can be produced only by duly proportioning the moving power to the load. It frequently happens, however, that some part of the machinery must be suddenly stopped, and as suddenly put into motion again, by throwing it out or into gear. But any sudden change in the load, requires a corresponding alteration in the moving power; and this object is completely attained by what is called the centrifugal regulator. The centrifugal regulator is composed of four bars, A B, A C, C D E and B D F, pinned or rivetted together, (see Misc. Plate, fig. 5.) the two longest bars having each a heavy weight fastened to its lower extremity.

The pin which fastens the two longest bars together, passes also through the vertical axis D H, on which is fixed a pulley at I.

On the axis of the fly wheel, at P, (see fig. 17, Pl. ii.) is fixed a drum wheel, round which and the pulley I, a strap is passed: by this means, the regulator is made to revolve round its axis with a motion proportioned to that of the fly wheel, and the weights E and F, are thrown out more or less, as the motion is more or less rapid. When the weights fly out, the extremity A is drawn down, and with it the end of the lever K L, attached to it; the other end being connected with the handle of the cock M, of the steam pipe B. By this means, the cock becomes partly closed, the admission of steam is checked, and the motion of the engine and fly wheel retarded.—On the contrary, if the motion be too slow, the weights fall down, the lever K L is thrown up—this opens the cock—the steam is admitted more freely, and the motion of the engine and fly wheel is accelerated.

The force of a steam engine is usually estimated by comparing it with that of a horse; thus we commonly say, a 20-horse power, or a 30-horse power. The principles upon which this calculation depends I will now explain to you.

The power of a steam engine depends on the degree of compression of the steam, the size of the cylinder, the length of the stroke made by the piston, and the number of strokes in a minute.

Let us suppose the diameter of the cylinder to be 31 inches, that the piston makes 17 double strokes of six feet each in a minute, and that the safety valve is loaded with nine pounds for every circular inch.—Then the estimate will be as follows:—

	lbs.
The force of the steam per circular inch	9
The area of the piston in circular inches 31 × 31 =	961
The product	8649

is the force exerted by the steam on the piston in pounds' weight.

Seventeen double strokes of six feet each =	204
The product	=1·764,396

is the power or momentum of the engine in feet and pounds' weight.

The power of a horse to draw is supposed to be equal to 200 pounds weight, at the rate of 2½ miles an hour, or 220 feet in a minute. But 200 × 220 gives 44,000 for the power of the horse, and dividing 1·764,396, the

momentum of the engine, by 44,000, the momentum of the horse, the quotient will be 40 nearly. Such an engine, therefore, will do the work of about 40 horses; and, as it may be made to act without intermission, and horses will not work more than eight hours out of the 24, it will perform the work of 120 horses; but since the work of a horse is equal to that of five men, it will perform as much work as 600 men. The expense of the coals used, and of the machinery, in its first cost and repairs, is equal to about half the number of horses for which it is substituted.

At first, the only thing to which steam engines were applied, was the raising of water from coal pits, mines, &c. to enable the workmen to proceed with their operations; but they are now used for a thousand different purposes in which great power is required. Mr. Boulton has applied this force to the machine for coining money, which, by the help of four boys only, is capable of striking 30,000 pieces of money in an hour, and the machine itself keeps an accurate account of the number struck.

ACOUSTICS.

LETTER XIX.

Acoustics defined and explained—The velocity of Sound—Distances of Objects ascertained by the velocity of Sound—Conductors of Sounds—Experiments—Of the Echo—Speaking Trumpet—Speaking Figures—Causes of the variety of Sounds—Eolian Harp—Smoke Jack—Winds.

FROM Pneumatics we naturally proceed to "Acoustics," a science which instructs us in the nature of sounds, that are usually conveyed to us by means of the air. In the infancy of philosophy, sound was held to be a separate existence, and brought to the organs of hearing, in a similar manner as the sensation of smell is conveyed to the nostrils. But so early as the time of Zeno, a different theory was advanced; this philosopher asserted "that hearing is produced by the air which intervenes between the thing sounding and the ear." "The air," he adds, "is agitated in a spherical form, and moves off in waves, and falls on the ear, in the same manner as water undulates in circles when a stone has been thrown into it." The discovery of the air-pump demonstrated that air, in general, was the vehicle of sound, because, as we have seen p. 148, a bell will give no sound in

vacuo, and one rung in condensed air gives a very loud sound. But air is not the only medium by which sound is conveyed to the ear; it will pass through water with the same facility with which it moves through the air.

EXPERIMENT I. A bell rung under water returns a tone as distinct as if rung in the air; and it has been ascertained by naturalists, that fishes have a strong perception of sound, even at the bottom of rivers. Hence it has been inferred that it is not material in the propagation of sounds, whether the fluid which conveys them, be or be not elastic.

It is found, by experiment, that sound travels at the rate of 1142 feet in a second, and that no obstacles hinder its progress, a contrary wind, only in a small degree diminishing its velocity; the method of calculating its progress is easily understood. When a gun is discharged at a distance, we see the fire long before we hear the sound; and if we know the distance of the place, and the time elapsed between our first seeing the fire and hearing the report, this will shew us exactly the time that the sound has been travelling to us. If a gun a mile off, be discharged, the moment the flash is seen, the seconds may, by a watch, be counted till the sound is heard, and the number of seconds is the time that the sound has been travelling a mile. By this means the distance of objects, otherwise immeasurable, may easily be found. Thus, if I see the flash of a gun in the night at sea, and count nine seconds before I hear the report, it follows that the distance is $1142 \times 9 = 10278$ feet, or nearly two miles. In the same way, the distance of a thunder-cloud is ascertained; for if the time be reckoned

from the moment we see the flash of lightning to that in which the thunder is heard, and multiply the seconds elapsed by 1142, we get the number of feet between our own situation, and that of the cloud. Some late observers, I ought to tell you, reckon only 1130 feet instead of 1142 feet, for the space which sound travels in a second.

Dr. Derham, who took great pains in investigating this subject, found that all kinds of sound travel at the same rate. The sound of a gun, and the striking of a hammer, are equally swift in their motions; the softest whisper flies as swiftly, as far as it goes, as the loudest thunder. Smooth and clear sounds proceed from bodies that are homogeneous, and of an uniform figure; and those which are harsh, from such as are of a mixed matter and irregular figure. The velocity of sound is to that of a brisk wind, as fifty to one.

It is thought that every substance is, in some measure, a conductor of sound; but it is certain that sound is much enfeebled by passing from one medium to another.

Ex. II. If a man stopping one of his ears with his finger, stop the other also by pressing it against the end of a long stick, or piece of timber, and a watch be applied to the opposite end of the stick or timber, be it ever so long, the beating of the watch will be distinctly heard; though perhaps the ticking of a watch cannot be heard in the usual way but a few feet.

Ex. III. The same effect will be produced, if he stop both his ears with his hands, and rest his teeth or temple against the stick or timber.

Ex. IV. Instead of a watch, a gentle scratch may be

made at one end of a long wooden rod, and the person who keeps his ear in close contact with the other end of it will hear it very plainly.

Ex. v. A person stopping both his ears as close as possible will hear the beating of a watch most distinctly, if he hold it between his teeth.

Ex. vi. If a person tie a poker or other piece of metal on to the middle of a strip of flannel, about a yard long, giving the ends a twist round a finger on each hand, and then pressing those fingers into the ears, and striking the poker against an obstacle, as a fender, he will hear a sound very like that of a large church bell: from this experiment it appears that flannel is a good conductor of sound.

The earth is also a conductor of sound: it is said, that by applying the ear to the ground the trampling of horses may be heard much sooner than it could through the medium of air only.

Sound is the effect which is produced on the ear, by the undulations of the air, and according as these undulations are stronger or weaker, the impression and consequently the sensation is greater or less. If sound be impeded in its progress by a body that has a hole in it, the waves pass through the hole, and then diverge on the other side as from a centre. But when sound, or the aerial waves meet with an obstacle which is hard, and of a regular surface, they are reflected; and consequently an ear placed in the course of the reflected waves, will perceive a sound similar to the original sound, but which will seem to proceed from a body situated in like position and distance behind the plane of reflection, as the

ical sounding body is before it. This reflected sound is called an echo.

If you throw a pebble into the water, waves spread from the point on all sides till they reach the margin; they are then thrown back again: the same thing happens with regard to the undulations of the air: they strike against any surface fitted for the purpose, as the side of a house, a brick wall, a hill, or even against trees, and are reflected: these reflections are the causes of an echo.

Ex. VII. If a bell, fig. 19, be struck, and the undulations of the air strike against the wall *c d*, in a perpendicular direction, they will be reflected in the same line, and if a person be situated between *a* and *c*, as at *x*, he would hear the sound of the bell by means of the undulations as they went to the wall, and he would hear it again as they came back after reflection, which would be the echo of the sound. A person, therefore, standing at *x* might, in speaking in the direction of the wall *c d* hear the echo of his own voice. It is found by experiment that sounds to be perceived very distinctly must not follow one another faster than at the rate of 9 or 10 in a second, that is, at the distance of $\frac{1142}{9} = 127$ feet nearly from each other; so that for the echo to be distinct the length *c x* must be 63 or 64 feet at least, in order that in passing from *x* to *c*, and returning from *c* to *x*, the distance may be 127 feet.

If the undulations strike obliquely against the wall, they will be reflected obliquely on the other side.

Ex. VIII. If a person stand at *m*, and there be any obstacle between that place and the bell, as at *z*, so as to prevent him from hearing the direct sound, he may ne-

vertheless hear the echo from the wall *c d*, provided the direct sound fall in that sort of direction as to force the reflected undulations along the line *c m*.

At the common rate of speaking we pronounce about three syllables and a half, or seven half syllables in a second; therefore, that the echo may return just as soon as three syllables are expressed, twice the distance of the speaker from the reflecting object must be equal to 1000 feet; for as sound describes 1142 feet in a second, $\frac{6}{7}$ths of that space, that is, 1000 feet nearly, will be described, while six half or three whole syllables are pronounced: that is, the speaker must stand nearly 500 feet from the obstacle: and, in general, the distance of the speaker from the echoing surface, for any number of syllables, must be equal to the seventh part of the product of 1142 multiplied by that number: thus, if eight syllables are to be repeated, we say $\frac{1142}{7} \times 8 = 1305$ feet for the distance of the speaker from the echoing surface. In churches and other confined buildings we never hear a distinct echo of the voice, but a confused sound, when the speaker utters his words too rapidly; because the greatest difference of distance between the direct and reflected courses is rarely in any church equal to 127 feet, the limit of echoes.

From the property of reflection of sounds, it happens that sounds uttered in one focus of an elliptical cavity are heard magnified in the other focus; instances of which are found in several domes, particularly in the famous whispering gallery of St. Paul's cathedral in London, where a whisper uttered at one side of the dome is reflected to the other, and may be very distinctly heard.

Hence we see the principle of the speaking and hearing trumpet; for when we speak in the open air, the effect on the ear of a distant auditor is produced merely by a single pulse of the air; but when we use a tube, all the pulses propagated from the mouth except those in the direction of the axis, strike against the sides of the tube, and every point of impulse becoming a new centre, from whence the pulses are propagated in all directions, a pulse will arrive at the ear from each of those points. Thus, by the use of a tube a greater number of pulses are propagated to the ear, and the sound is consequently increased. Or it may be that by instruments of this sort sound is, as it were condensed, for all the waves that fly off from the sides of a sounding body, are by the trumpet condensed into one, which makes its force so much greater.

An umbrella, held in a proper position over the head may serve to collect the force of a distant sound by reflection, in the manner of a hearing trumpet, but its substance is too slight to reflect any sound perfectly, unless the sound fall on it in a very oblique direction. The exhibitions of speaking figures, and of the invisible girl, are performed by conveying the sound through pipes artfully concealed, and opening opposite to the mouth of a trumpet, from which it seems to proceed.

We have already seen that pendulums of equal length move in equal times, though they pass through different arcs, that is, fig. 20, if the pendulums A B and C D are equal, the time of passing through E F is equal to that of passing through G H: and the vibration of the string I K, fig. 21, may be considered as a double pendulum,

oscillating from the points K and I, the vibrations of which from the greatest to the least are performed in the same time, which is the reason why a musical string has the same tone from the beginning of the vibration to the end. The tone of a sound depends on the time that the impression dwells on the ear, or the time that the string vibrates: thus the longest strings have the longest vibrations, and produce the gravest sound: the shortest strings have the shortest vibrations, occupy less time, and have the sharpest sound.

There are three principal causes of the variety of sounds: (1) the greater or less frequency of the vibration of sonorous bodies; (2) the quantity or force of the vibrating particles; and (3) the greater or less simplicity of the sounds: hence are derived the height, strength, and quality of sounds.

If a rope 30 or 40 feet long be stretched pretty tight between two points as *a* and *b*, fig. 22, and struck smartly with a stick, the whole rope will not vibrate from end to end, but there will be found several still places in it, between which the parts of the rope will vibrate, as from *a* to *c*, and from *c* to *d*: the distance of these stationary places is always an even part of the whole rope; as from *a* to *d* is half, from *c* to *d* one fourth, and so on.

Hence the fine sounds produced by the Eolian harp; for though there be many strings, and all tuned in unison, yet we hear not only the natural sound of each string, but its octave, fifth, third, twelfth, &c. The current of air striking upon these strings may be considered as a violin bow, and thus each string is divided into a number of imaginary bridges, to which it has a

natural tendency. Hence every string becomes capable of several sounds: if every string were of the same length, magnitude, and tension, the vibrations would uniformly coincide, and produce perfect unison. If the strings were in proportion of 2 to 1; that is, if the shorter string is half the length of the longer, and makes two vibrations, while the shorter makes but one: these are called octaves. If the vibrations be to one another as 2 to 3, the coincidence will be at the third of the shorter string, and in music it is called a fifth. When two strings of equal tone are placed near one another, on striking one, the pulse or undulatory motion of the air will produce a sympathetic sound in the other. So in the Eolian harp, if only two of its strings are in unison, and a piece of paper be hung on one of them, all the other strings may be struck without effect; but when the unison string is struck, the paper instantly leaps off from the other.

Wind you know is air in motion, and whatever excites that motion, will produce wind. There are probably many causes which conspire to produce the effect, but the heat communicated by the sun is the principal. Heat expands all bodies; it therefore rarifies the air, and makes it lighter: but as you have seen, the lighter fluids always ascend, and thereby leave a partial vacuum, toward which the surrounding heavier air presses, with a greater or less motion, as the degree of rarefaction or of heat which produces it, is greater or less.

Ex. IX. Take a lighted wax taper, or candle, and hold it at the bottom of the door of a room in which there is a fire; then hold it at the top, and afterwards about the middle, and you will find that at the *bottom*

the flame is brought *into* the room; at the top it rushes out: and in the middle it is nearly or wholly stationary, having no tendency either way.

The reason of this experiment is, that the heat of the fire rarifies the air, which ascends, leaving a partial vacuum at the lower part of the room; to supply the deficiency, the dense air rushes in at the bottom, driving the flame of the taper inwards, and the lighter particles are driven out at the top of the door by the pressure of the heavier ones from beneath.

The smoke jack, as it is called, depends on this principle; it is worked by means of the current of air constantly ascending the chimney, which current is produced by the heat of the fire, and not by the smoke, and striking against the leaves of a sort of ventilator, turns the chain, spit, &c.

Wind then is a current of air generally produced by the heat of the sun, and its direction is denominated from the quarter from which it blows; thus when it blows *from* the north or south, we say it is a north or south wind.

There are usually reckoned three kinds of winds, independently of the names which they take from the points of the compass from which they blow: these are the *constant*, or those which always blow in one direction: the *periodical*, or those which blow six months in one direction, and six in a contrary one; and the *variable*, which appear to be subject to no general rules.

The *constant* winds are found in that large tract on the globe, that lies between 28° or 30° north and south of the equator, they follow the apparent course of the sun which is always vertical, or nearly so, to some

part of this tract of our globe, and since the wind follows the sun it must blow in one direction, or easterly. These constant winds are likewise denominated trade-winds.

The periodical winds prevail in several parts of the Eastern and Southern oceans, and depend on the sun; for when that body is north of the equator, that is, from the 20th of March to the 20th of September, the wind sets in from the south-west, and the remainder of the year, while the sun is south of the equator, the wind blows from the north-east. These are called "the Monsoons," or shifting trade-winds, and they are of much importance to those who make voyages to the East Indies.

OPTICS.

LETTER XX.

Optics—Light—Velocity of Light—Its motion—Refraction of Light explained—Consequences and Advantages of Refraction—Entertaining Experiments.

In the science of optics every thing depends on light, which is supposed to consist of inconceivably small particles, thrown off from a luminous body, with great velocity, in all directions. They diverge in right lines till they are inflected by the attraction of some other body, or refracted by passing obliquely through a medium of different density, or reflected by the intervention of an opposing body, and therefore, the particles of which light is composed being governed by the power of attraction, in the same manner as the particles of other matter, it has been inferred that they also are material. They must, however, be indefinitely small, from the circumstance of their penetrating the densest bodies, such as glass, the diamond, &c., and also from this circumstance, that the greatest number of them that can be collected, are not found to have any the smallest sensible weight.

It is evident that the rays of light are emitted in right

Fig 15

Fig 16

Fig 18

Fig 17

Fig 20

Fig 21

Fig 22

Cooper sculp

lines, from the shadow which is thrown behind those bodies on which they fall, as the corresponding parts of the substance and shadow form right lines with the ray. Besides, light will not pass through a bended tube.

It was formerly supposed that the velocity of light was instantaneous, but it has been one of the discoveries of modern times, that notwithstanding its swiftness is so great as to prevent its passage from one visible object to another from being marked by any difference of time, yet its motion is certainly progressive, and at the rate of 200,000 miles in a second of time. For it is observed that the eclipses of Jupiter's moons vary about 16 minutes of time in certain positions of the earth in its orbit, being eight minutes sooner than the calculated time, when the earth is nearest the planet, and eight minutes later than the tables when the earth is in the opposite part of its orbit.

Let *s*, fig. 1, Optics, Plate 1, be the sun from which the tables are made, and A B C the earth's orbit; E Jupiter, and D one of his satellites entering his shadow. An observer at the sun would find the time of his immersion coincide with the tables, but to a person at A it will take place eight minutes sooner than at S, and to one at C it would be eight minutes later; hence it is inferred that the rays of light are 16 minutes in passing through A C, the orbit of the earth, or 8 minutes in passing from the sun to us, or 95 millions of miles,* which is at the rate of 200,000 per second nearly; this is about a million and a half times faster than the velocity of a cannon-

* 95,000,000 ÷ 8 × 60 = 200,000 nearly.

ball, which may be supposed to go at the rate of eight miles in a minute.

Notwithstanding this velocity, which surpasses every effort of the understanding to comprehend, philosophers have conjectured that there may be stars, which, we shall show in a future letter, are suns to other worlds, so distant from us that the light proceeding from them has not yet reached the earth, though it has been travelling at the rate of 200,000 miles per second from the first creation of all things.*

The particles of light move in all directions, without appearing to jostle one another in their course.

EXPERIMENT I. Take a sheet of brown paper and make a small hole in it with a pin or needle, and look through it, you will see numerous objects almost as well as if no paper were interposed between them and the eye. Now as we only see objects by means of the rays of light which flow from them, the rays that come from a landscape, for instance, seen by looking through the small hole in the paper must come in all manner of directions at the same time.

EX. II. If a candle be placed on an eminence in a dark night, it will illuminate a space for half a mile round; in other words, there is no place within a sphere of a mile in diameter, where the candle cannot be seen, that is, where some of the rays from the small flame will not be found. These will be stronger or weaker in

* The young arithmetician may calculate the distance which a ray of light will have travelled at this rate from the creation to the present time, allowing 4004 years to have elapsed from Adam to the birth of Christ, and 1821 years since.

proportion as the distance from the candle is less or greater. For the intensity or degree of light decreases as the square of the distance from the luminous body increases; that is, the light from any luminous body, at 1, 2, 3, 4 yards, miles, &c. distance, will be diminished in proportion to the squares of those numbers, or as 1, 4, 9, 16, &c., in other words, the light of a candle will be 4 times less at the distance of two yards than it is at a yard distance only, and sixteen times less at 4 yards distance. It is the same with regard to the light from the sun; thus the planet Saturn is nearly 10 times as far distant from the sun as the earth, therefore it will receive only one hundredth part of the light and heat of the sun that we enjoy. Again, the Herschel planet is twice the distance of Saturn from the sun, and will of course enjoy only the fourth part of the light and heat which that planet experiences, or the $\frac{1}{400}$th part of what we enjoy.

By "a ray of light" is meant one of the particles of light in motion, and its motion being rectilinear is properly represented by a straight line. But the rays of light are subject to the laws of refraction and reflection.

If the rays of light, after passing through a medium enter another of a different density perpendicularly, they proceed through this latter medium in the same direction as before; but if they enter the second medium in an oblique direction, they are bent out of their course, and this is called *refraction.*

Ex. III. Suppose A B, fig 2, to be a piece of glass an inch or two thick, and a ray of light, S *a*, to fall upon it at *a*, it will not pass along the line S *s*, but will, at *a*, be bent out of its course towards the perpendicular, and

proceed to *x*. But a ray, P *a*, would proceed straight on to *b*, because in this case there is no refraction.

Rays of light may pass from a rarer to a denser medium, as from air into glass or water; or they may pass from a denser into a rarer, as from water into air.

When a ray of light passes out of a rarer into a denser medium, it is, as we have seen, drawn nearer to the perpendicular. But when it passes from a denser medium into one more rare, it moves in a direction farther from the perpendicular; thus, if the ray *x a* pass from glass or water into air, it will not, when it comes to *a*, move in the direction *a m*, but in the line *a* s, which is farther than *a m* from the perpendicular *a* P. You will not forget "that we see every thing by means of the rays of light which proceed from them."

Ex. IV. Take a common upright earthen pan, and on the bottom, place a shilling, with a small piece of wax to keep it from slipping, now move backward till the side of the pan deprive you of the sight of it; let another person pour water into the pan, and you will immediately see the shilling.

This experiment is easily explained by the figure just referred to: conceive your eye at s, and *a a* the side of the pan, and the piece of money to be at *x*; now, when the pan is empty, the rays of light flowing from *x*, must go in the direction *x a m*, at least they cannot pass in the direction *a* s, of course the side *a a* prevents an eye at s from seeing the spot *x*. But as soon as water is poured into the vessel, the rays of light proceed from *x* to *a*, and there, entering from a denser to a rarer medium, they will be bent *from* the perpendicular into the

line *a* s, and the eye at s will see the shilling at *x*, or rather the rays of light proceeding from it, and it will appear to be situated at or a little higher than *n* instead of *x*.

It may seem strange that though the shilling has not moved from *x* that it appears at *n*, but it is an axiom in optics, "We see every thing in the direction of that line in which the rays approach us last."

Ex. v. Take two looking-glasses and place a candle before one of them, so as that the image of the candle may be reflected to the other, and if you look into that glass you will suppose the candle behind it, because this is the direction whence the last rays come to the eye.

From the fourth experiment we learn the reason why an oar always appears bent in the water; for if *m a x* were a straight oar, it would, in water, appear bent like *m a n*, and raised higher in the water than it really is: it is on this account that a fish in a pond, river, &c. appears nearer the surface than it actually is; and for the same reason, any water will appear to be much shallower than it is. This is a fact that ought to be generally known by young persons, who, without being able to swim, may venture, at the risk of their lives, in water six feet deep, thinking it only between 4 and 5 feet; for the bottom, where the water is clear, always appears one-fourth nearer the surface than it really is. By carefully attending to the experiment of the shilling and pan you will see the money rises apparently in the water, as well as it changes its other relative position.

To the principle of refraction we are indebted for

many advantages that we daily and hourly enjoy, but for which we are rarely so thankful to a beneficent providence as we ought. The sun is seen before he comes to the horizon in the morning, and after he sinks beneath it in an evening, by the refractive power of the atmosphere, by which our days are lengthened and our eyes preserved from that dazzling splendour which must be highly injurious to them if we passed immediately from darkness to the glare of the sun, which would be the case if there were no atmosphere.

Hence we never see the sun and moon in the places where they really are situated, they always appear higher than they are, as the oar does in water; thus, a person standing at *a*, fig. 3, would see the sun rise at *b* when it was in reality only at *c*; if at *a* he had the sun in his zenith, he would in that case see him where he really is, for his rays would come perpendicularly through the atmosphere, but that never occurs in this country with regard to the sun and moon.

Ex. vi. Take a glass goblet half full of water, throw a shilling into it, and then, having placed a plate over it, let it be quickly inverted. A bye-stander, unacquainted with the laws of refraction will suppose that he sees a shilling and half-a-crown, the former is seen by the rays after refraction at the surface, the latter is seen by means of rays coming through the water at the side of the glass, and therefore the image is magnified; the reason of which you will hereafter readily understand.

LETTER XXI.

Description and Uses of Lenses—Their effect—Method of finding the Focus of a Lens—Burning-glasses described, with the Effects produced by them—Experiments—Imaginary Focus defined—Axiom in Optics—Image by Reflectors when formed—Anamorphoses.

I SHALL now, my young friend, describe to you the different kind of lenses made use of in optics. A *lens* is a glass ground into such a form as to collect or disperse the rays of light which pass through it. A *plano-convex* lens has one side flat and the other convex, as A, fig. 4. B is a *plano-concave* lens, having one side flat and the other concave. A *double-convex* is convex on both sides, as C. A *double concave* lens is concave on both sides, as D. A *meniscus* is convex on one side and concave on the other, as E, of which a watch-glass is an example.

The axis of a lens is a line passing through its centre; thus F G is the axis to all the several lenses. The effect of these several kinds of lenses is to cause the rays of light that pass through them to converge or diverge.

Rays are said to *converge* when they continually approach to each other; thus, fig. 5, the parallel rays *a a*; *b b*; *m m* falling upon the plano-convex lens *c x d*, approach each other till they meet in C. But if a candle be placed at C, before a small hole, then the rays in going to the side of the lens *c n d*, will recede from one another

that is, they diverge. The point c in optics is called the focus.

I will explain the manner in which the focus is found in those kind of lenses which are chiefly in use. To begin with the most simple. Parallel rays falling upon a plano-convex lens meet at a point behind it, the distance of which, from the centre or middle of the glass, is exactly equal to the diameter of the sphere, of which the lens is only a portion; thus in fig. 5, a circle is made, in which the lens, *c x d n*, will fit, and therefore c is the focus.

The reason of this is obvious; for rays of light passing out of a rarer to a denser medium incline to the perpendicular; therefore the rays *a a*, *b b*, &c. passing from air into glass, must incline to the perpendicular, c *x b*, till they all meet in c, and if nothing be at the point to stop them they will cross each other, and the perpendicular c *x b*.

The distance of the focus of parallel rays, of a double convex lens, is equal only to the radius of the sphere, see fig. 6; for two convex surfaces must have double the effect in refracting rays that a single one has; and as the latter brings them to a focus at the distance of the diameter, the former will do the same at half that distance, or of the radius.

A common burning glass is a double convex lens and acts upon this principle, that all the rays of the sun, which fall perhaps on a surface of three or four or more square inches are by means of the convexity brought to a point *f*, of only $\frac{1}{4}$ or $\frac{1}{8}$ of an inch, so that the heat at the focus will be 10 or 100 or 1000 times as great at

the focus as it is at the surface, according to the size of the glass. The heat collected by very large burning glasses, as that made by Mr. Parker for Dr. Priestley, is such that nothing can withstand. This glass was nearly three feet in diameter, and it produced a heat that melted iron plates in a moment: all resinous substances it instantly melted under water; and a variety of other substances it changed into transparent glass. The heat produced by this lens fused 20 grains of gold in four seconds: of silver in three seconds: ten grains of platina in three seconds, and as much flint in thirty seconds.

If the parallel rays at B, fig. 6, fall on the double convex lens, they will converge and meet in *f*, where they will cross one another, and diverge: and if another convex lens F G be so placed as to receive the diverging rays, they will be made to converge, and then proceed out of it in parallel lines *b c*.

If a candle be placed at *f*, the focus of the convex glass, the diverging rays in F *f* G or D *f* E will be so refracted by the lenses, that after going out of them they will become parallel again. But if the candle be at *g*, fig. 7, the rays will diverge after they have passed through the glass, and the divergency will be greater or less in proportion as the candle is more or less distant from the focus: and if it be placed farther from the lens than the focus, as at *g*, fig. 8, then the rays, after passing the lens, will meet somewhere as at *x*; and this point will be more or less distant from the glass, as the candle is nearer to, or further from its focus, and where they meet they will form an inverted image of the flame of the

candle, because that is the point in which the rays, if they are not stopped, cross each other.

EXPERIMENT. I. These things may be shewn to the senses by means of a common burning glass, which A B, fig. 8, will represent; and if the candle be at *g*, the inverted image of it may be taken on a piece of writing paper, held at *x*. And if the candle be brought nearer to *f*, the image at *x* will be carried farther off.

The general rule for finding the place of the image or picture of an object is this, supposing the focal distance of the glass to be known:

"Multiply the distance of the focus by the distance of the object, and divide the product by their difference, the quotient will be the distance of the picture. Thus if the focus of a glass be six inches, and an object be placed at 15 inches distance, the picture will be found to be $\frac{15 \times 6}{9} = 10$ inches."*

The picture will be as much larger or less than the object, as its distance from the glass is greater or less than the distance of the object: which may be thus explained:

EX. II. Let A B C, fig. 9, be any object, as an arrow placed beyond the focus F, then rays from every part

* Hence the reason why, when the candle is placed in the focus of the lens, the rays go out parallel; because, then the difference of the two quantities mentioned in the rule is *o*, or nothing; and any quantity divided by *o* gives an infinitely large number; thus 1 divided by $\frac{1}{2}$ give 2: divided by $\frac{1}{10}$ gives 10, and as the divisor diminishes, the quotient increases, so that when the former is infinitely small, or nothing, the latter is infinitely large, or the lines do not converge till at an infinite distance, that is, they never meet—in other words, they are parallel.

will flow from it, as represented in the three points A, B, C, and in passing through the glass they will be refracted, and meet in the points *a b c*: viz. the rays that flow from A are brought to a focus at *a*; those from C at *c*, and the rays flowing from the intermediate points between A and C are brought to their different foci between *a* and *c*. Now, if the object A B C is brought nearer to the glass, the picture will be removed to a greater distance, and will increase also in magnitude: when the distance B x = b x, then the object and picture will be equal to one another; but if b x be greater than B x, then the picture is larger than the object. In all cases, to obtain a picture or an image, the object must be beyond the focus F, for, if it be at F, then the rays will go out of the glass parallel to one another as in fig. 6: and if it be nearer, as in fig. 7, then the rays will go out diverging, and in neither case will a picture be formed.

There are also concave lenses, as you have seen, and the refraction occasioned by these is very different from that by convex glasses.

Ex. III. Suppose the parallel rays *a b c d*, &c. fig. 10, to pass through the double concave lens A, B, they will diverge after they have passed through the glass, and precisely so much, as if the rays had come from a radiant point x, which is the centre of the concavity of the glass. This point is called the *imaginary* or *virtual* focus. The ray *a* after passing through the glass A B will go on in the direction *g h*, as if it had come from x, and no glass in the way: the ray *d* would proceed along *r t* in the same manner, and so of the rest. The centre *a c x* suffers no refraction, but proceeds precisely as if no glass had been interposed.

If the lens had been concave only on one side, and flat on the other, the rays would have diverged after passing through it, as if they had come from a radiant point, at the distance of a whole diameter of the convexity of the lens.

Hence you will observe, that the *focus* of a double *convex* lens is at the distance of the radius of convexity, and so is the *imaginary focus* of the double *concave*: the *focus* of a plano-convex is at the distance of the diameter of the convexity, so likewise is the *imaginary focus* of the plano-concave.

We come now to reflected light. When rays of light strike against a surface, and are sent back from it, they are said to be reflected. The ray that comes from any luminous body and falls upon a reflecting surface is called the incident ray; thus the rays, S *a* or P *a*, fig. 2, falling upon the reflecting surface A D, is called the incident ray.

Ex. IV. When the ray, as P *a*, falls perpendicularly on the surface, it is reflected back again in the same line; hence if a person stand before a looking glass he sees his own image, because the rays proceeding from him to the glass come back again to his eye in the same line.

Ex. V. When the ray, as S *a*, falls obliquely on the surface, it passes off in the direction *a* E, making the angle E *a z* equal to S *a z*: hence a looking glass being placed at the end of a room, a person sitting or standing on one side of the room will see in the glass the furniture of the opposite side: that is, if A B be a looking glass, and a person sit or stand at S, he will not see his own image in the glass, but will see the image of the point E,

and a person at E will see the image of the objects at S.

You may regard it as an undeviating maxim, that *the angle of incidence is always equal to the angle of reflection, whether it be with regard to plane or spherical surfaces, concave or convex.*

Ex. VI. When a person stands before a looking glass, he sees the image of himself apparently as far behind the glass as he stands before it: for it is the distance that the ray travels backwards and forwards which ascertains the distance of the image from the object; thus, a man at A C, fig. 11, standing before a looking glass, *a b*, will see the image of himself at B D: for the ray passing from his eye to *a* is reflected back again in the same line to the eye, and has travelled through a distance equal to twice A *a*=*a* B, the ray proceeding from the foot C, falling obliquely on the glass, at *b*, is reflected along the line *b* A to the eye: here the distance which the ray travels is C *b*+*b* A, therefore the image of C will be seen at D. (1) because A D is equal to A *b*+*b* C: and (2) because, we see every thing in the direction of that line in which the rays approach us last; for the image of C being reflected to the eye through the line *b* A, we must see it in the direction of the line A *b* D, or at D. The same may be proved of the intermediate parts between A and C.

Hence, by referring to the figure, you will readily understand why a person may see a perfect image of himself in a looking glass only half as high as he is tall, and the thing is easily proved by a theorem in geometry; for since A B is equal to twice A *a*, therefore B D, or its

equal A C, is equal to twice *a z*, which is the part of the glass by which the rays of light are transmitted to the eye.

If you move forwards and backwards before a looking glass, the image of yourself seems to approach and recede, but with double the velocity of your own motion; because the eye will be affected with the motions of the object and its image, which are equal and contrary.

Ex. VII. In looking at the reflection of a candle in a looking glass, if we stand a little sideways, we see two images, one weaker than the other; which is occasioned by reflections from the upper and under surface of the glass—the former giving the faint image, and the latter, or the silvered part, the vivid one.

In reasoning on these subjects, we say the image is formed behind the reflector, because the reflected rays come to the eye precisely with the same inclination as they would if the object itself were actually behind the reflector. The image, however, is not so vivid as the object; because, though a plane mirror, or looking glass, is, in theory, supposed to reflect all the light which falls upon it, yet, in practice, nearly half the light is found to be lost on account of the inaccuracy of the polish.

Rays of light coming from the sun are supposed to be parallel to one another; and on this supposition we build our theory of reflected light by means of spherical mirrors.

When parallel rays fall upon a concave mirror they will be reflected, and meet in a point at half the distance of the surface of the mirror from the centre of its conca-

vity. If the parallel rays, *a b*, c *m d*, and *e f*, fig. 12, fall upon the concave mirror A B, then *a b* will be reflected along *b m*; c *d* will be reflected along *d m*, and *e f* along *f m*, and therefore they all meet in *m*, and *m d* is found to be equal to *m* c or the half of c *d*.

Since the rays proceeding from any celestial object are parallel, the image of the sun, star, &c., will be found at *m*, half way between the mirror and its centre of concavity, and the image will be inverted with respect to the object, because the rays cross each other. And it is a general rule, that when the image of an object is formed by a speculum, if the rays, after reflection, converge to an actual focus, the image is inverted; and, therefore, as in the instance when they converge to the point *m*, the image is inverted and less than the object, as will be evident by fig. 13, where A represents the actual image of the candle B, formed by the concave mirror C.

If the rays diverge from a vertical focus, the object will be erect, and at the centre of the speculum, the object and image subtend equal angles; but if the object B, fig. 14, be nearer the speculum than the centre of concavity, then the image A will not only be erect but magnified.

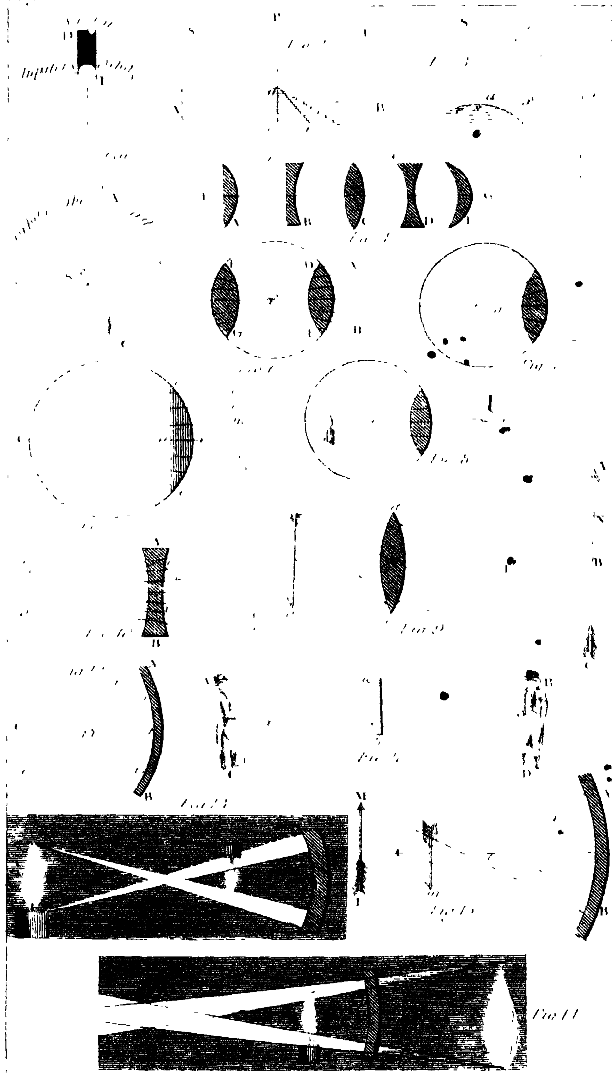
Hence the rays which proceed from a remote terrestrial object M E, fig. 15, will, after reflection, converge at a little greater distance than half way between the mirror and the centre of concavity, and the image will be inverted with respect to the object.

If the object M E, move to the centre C, the image and object coincide; hence the following experiment:

Ex. VIII. If you stand before a large concave mirror, beyond its centre of concavity, you will see an inverted image of yourself suspended, as it were, in the air, and by extending your hand towards the mirror, the hand of the image will come out and coincide with it. But thrust your hand beyond the centre of concavity the image will pass beyond it, because as the object M E in the figure moves beyond C towards the mirror, the image *e m* moves beyond C from the mirror.

A convex mirror always forms a virtual image of a real object, which is erect and smaller than the object. A, figure 14, may be considered as a candle before a convex mirror C, and B will be the image. You will perceive that the image is formed behind the glass, and as a person walks towards a convex spherical reflector, the image appears to walk towards him, constantly increasing in magnitude till they touch each other.

There are other reflecting surfaces besides the plane, the regular convex, and the regular concave, and the images formed by them are called *anamorphoses*; these are produced from cylindrical concave mirrors, and as the mirror is placed upright or on its side, the image of the picture is distorted into a very long or very broad image. If a regular figure be placed before an irregular reflector the image will be deformed; but if an object, as a picture, be painted deformed, and agreeably to certain rules, the image will appear regular. Such figures, and reflectors suited to them, are readily obtained at the shops of most of our opticians.



LETTER XXII.

Light, of what composed—different refrangibility of the rays—Experiments with the prism—the Rainbow explained—Structure of the Eye—Uses of the several Parts—why Objects are seen erect—Causes of indistinct Vision pointed out.

We have hitherto considered light as a simple body; and have supposed that all light in passing out of one medium into another is equally refracted in the same or like circumstances. Such was the general opinion, till the discoveries of the immortal Newton, who in the course of his investigations found that light is not a simple homogeneous body, but is compounded of different species, distinguished from each other by their colours; and that each species suffers a different degree of refrangibility, in passing out of one medium into another, and excites also in the mind the idea of a different colour from the rest. It is also known by the most decisive experiments, that those rays which are most refrangible, are likewise most reflexible, or most easily turned back. In other words, the sun's light consists of rays which have a considerable inequality of refraction as they are transmitted through the medium of the atmosphere, and impress a sensation of colours as they are more or less bent in their course, which we call *violet*, *indigo*, *blue*, *green*, *yellow*, *orange*, and *red*. The latter or red rays are the least refrangible, and the violet the most refrangible, and the intermediate colours have also intermediate

degrees of refrangibility. These are all the primary colours in nature; some writers, indeed would reduce the seven to three, namely to the red, the green, and the violet: but whether they be three, or seven, it is certain that all other tints whatever are produced by the mixture of these. Whiteness is produced by a copious reflection and due proportion of all the colours; and blackness proceeds from the peculiar quality of a body which stifles and absorbs the rays of light that fall upon it; so that, instead of reflecting them outwards, they are reflected as it were inwards till the incident rays are lost.

The principle of colours may be illustrated and explained by means of a glass prism, which is a solid piece of glass, with three flat sides, through which the sun's rays are refracted.

EXPERIMENT I. If a ray of light S, fig. 16, be admitted into a darkened room, through a small hole in the shutter *x y*, its natural course is along the line S *d*; but if the glass prism *a b c* be placed to receive the ray, it will be bent upwards, and if it be taken on any white surface, M N, it will form an oblong image P T, the breadth of which is equal to the diameter of the hole in the shutter. In this oblong you will observe the seven colours, viz. the *red* at the bottom, which is least bent out of its course, then the *orange*, *yellow*, &c. till you come to the *violet*, which is the most refrangible, or that which is most bent out of its course.

If the ray had been of one colour only, it would have been equally bent upwards, and made only a small circular image. But since the image or picture is oblong, it is inferred that it is formed of parts differently refrangi-

ble, some of which are turned more out of the way than others, those which go to the upper part of the spectrum being, as we have seen, the most refrangible, and those which go to the lowest part, the least refrangible. If the spectrum be received on a perforated plane, so that the simple colours may be allowed to pass each distinctly through the hole, it will be found that they still preserve their colour though they are refracted by another prism upon some other surface.

If the prism be so placed that the ray of light proceeding from S, pass through the hole in the shutter as to be reflected, the violet rays will be the first reflected, and the red the last.

There is a remarkable analogy between colours and sound, for the divisions of the uncompounded colours on the spectrum agree exactly with the different divisions of a musical chord. The divisions on the spectrum are in the following proportions: supposing the whole divided into 360 parts, the red will occupy 45 parts, the orange 27, the yellow 48, the green and blue 60 each, the indigo 40, and the blue 80.

Ex. 2. If a circular surface be divided into 360 parts, and painted according to the proportion just mentioned; and then a quick motion be given to it, the whole will appear of a dirty white; and if the colours were more perfect, the mixture of them by this circular motion would give a more perfect white also.

From the refraction and division of the rays of light into their original primary colours by means of drops of rain, which act as so many prisms, the rainbow is produced.

Ex. III. If A, fig. 17, be a drop of rain, and S d a

ray from the sun falling upon, or entering it at *d*, it will not go to *c*, but be refracted to *n*, where a part will go out, but a part also will be reflected to *q*, where it will go out of the drop, which acting as a prism, separates the ray into its primitive colours: the violet will be uppermost and the red the lowermost. The ray S *d*, if uninterrupted by the drop A, would proceed to C, but by the refraction at *d*, the reflection at *n*, and the refraction at *q*, the rays are separated into the primitive colours, the violet ray *x q* extended to *c*, makes an angle with S *c* of 40° .. 17′, and the red ray *g q*, extended to *f*, makes with S *f* an angle of 42° .. 2′: and the other coloured rays will be found somewhere between these.

The situation of the rain-bow varies according to the height of the sun: that is, the higher the sun the lower the rain-bow. You will frequently observe two rain-bows at the same time: the strong and vivid one, which is formed in the way now explained; and the other fainter, which is formed by two reflections and two refractions: thus if the ray T *r* enter the drop at *r*, it is refracted to *s*, where it is reflected to *t*, and from thence again reflected to *u*, where it comes out of the drop, and is divided into its primary rays, the violet being the lowest, and the red ray the uppermost.

The same circumstances take place with respect to a whole shower, which has been shown with regard to a single drop, and by the constant falling of the rain the image is preserved perfect. In figure 18, we have a representation of the two bows. The rays come in the direction S A, and the spectator stands at E, with his back to the sun. In other words, to see a rain-bow we

must be situated between the sun and the shower, of which it is formed.

Artificial rain-bows may be exhibited with a common watering-pot, or with a syringe fixed to an artificial fountain. It is often seen in cascades, and even in the foam of a rough sea. The colours observable on soap-bubbles, and the halos which sometimes surround the moon, are to be referred to the same origin.

I will now call your attention to the structure of the eye, and the uses of its several parts in vision. It is of a globular form, and composed of three coats, covering one another, and inclosing different substances, called humours. The three coats are the *sclerotica*, the *choroides*, and the *retina*: and the three humours are the *aqueous*, the *crystalline*, and the *vitreous*. Thus, fig. 19, A B C D E, represents a section of the eye; the three concentric circles, the three coats; the external one is called the *sclerotica*, of which C *x* D is a part denominated the cornea. Underneath the *sclerotica* is the *choroides*, which is divided into two parts, that in front, which is sometimes blue, sometimes brown, sometimes black, is called the *iris*, and the back part, the *choroides*. The third or inner coat Z, is the *retina*, which is an expansion of the medullary part of the optic nerve A, and serves to receive the images of objects produced by the refraction of the different humours of the eye, and painted, as it were, upon its surface. A is the optic nerve intended to convey to the brain the sensation produced upon the retina.

The cornea, or white of the eye, is represented fig. 20, by *c*, the iris *a b* is composed of two kinds of muscles,

the one tending to the centre, and the other forming a number of concentric circles round the same centre. The central part of the iris is perforated, and the orifice, which is denominated the *pupil*, varies in magnitude by the action of the two sets of fibres composing the *iris*, which action is affected by the quantity of light to which the eye is exposed. In a dark room the radial fibres of the iris contract, and the pupil is large, but in the glare of the sun the circular fibres contract, and make the pupil very small.

The three humours of the eye are denominated the *aqueous*, *crystalline*, and *vitreous* humour. The aqueous is the most fluid, being thin and clear, like water, whence it takes its name, and fills up the space immediately behind the cornea, and it is divided into two portions by the iris, which seems to swim in it. The crystalline, which answers to *d f*, fig. 19, is a double convex lens, contained in a strong and transparent membrane, and suspended behind the aqueous humour by a certain ligament. The vitreous humour receives its name from its appearance, which is like melted glass. It is not so hard as the crystalline, nor so liquid as the aqueous humour: it fills all the interior of the eye *m*, *n*, behind the crystalline humour. Such is the structure of the eye: the eye-brows defend the eye from too strong a light; and they prevent the eyes from injuries by the sliding of substances down the forehead: and the eye-lids act like curtains to cover and protect the eyes during sleep; in our waking hours they diffuse a fluid over the eye-ball which keeps it clean, and well adapted for transmitting the rays of light: and the eye-lashes, in a

thousand instances, guard the eye from danger, and protect it from floating dust with which the atmosphere abounds.

Objects are seen by means of their images which are painted on the retina of the eye: thus an object, as an arrow, A B C, fig. 21, sends out rays that fall on the cornea of the eye, between E and F, and by passing on through the pupil and humours, they will be converged to as many points on the retina, and will there form a distinct inverted picture, *c b a*. For the pencil of rays *m n o* flowing from A will be converged to the point *a* on the retina; those from B will be converged to the point *b*; those from C to the point *c*, and so of the intermediate points; by which means the whole picture *a b c* is formed, and the object becomes visible. Though the images of objects are painted on the retina in an inverted state, yet they are seen erect, so that the mind is never deceived with respect to the position of objects. The reason of this curious phenomenon has never been completely explained; but in the fifth volume of the Scientific Dialogues, Conversation XVI. the subject is illustrated in a familiar manner with a number of apposite examples.

On this subject Dr. Young, in his Lectures, vol. i. p. 449, observes, that "Opticians have often puzzled themselves, without the least necessity, in order to account for our seeing objects in their natural erect position, while the image on the retina is really inverted; but surely the situation of a focal point at the upper part of the eye could be no reason for supposing the object corresponding to it to be actually elevated. We call

that the lower end of an object which is next the ground; and the image of the trunk of a tree being in contact with the image of the ground on the retina, we may naturally suppose the trunk itself to be in contact with the actual ground. The image of the branches being more remote from that of the ground, we necessarily infer that the branches are higher, and the trunk lower: and it is much more simple to compare the image of the floor with the image of our feet, with which it is in contact, than with the actual situation of our forehead, to which the image of the floor on the retina is only accidentally near, and with which indeed it would perhaps be impossible to compare it, as far as we judge by the immediate sensations only.

You will now readily perceive the causes of indistinct vision, and understand the remedies that are applied. To see an object distinctly, it is necessary that every pencil of diverging rays, which comes to the eye from the object, should be converged to a point on the retina, corresponding to that from which the rays have diverged. If these are converged too soon, or before they reach the retina, or are not converged till they get beyond the retina, then the vision is indistinct: these defects are occasioned by the eyes being either too convex, or not sufficiently convex. When they are more convex than necessary, concave glasses or spectacles are used, and when they are too flat we have recourse to convex spectacles.

LETTER XXIII.

Colours of Bodies explained—Light the cause of Colour—Colours of Flowers explained—All Bodies when very thin are partially transparent—Opake Bodies how rendered transparent—Colours of the Cameleon explained—Colours of the Sky and Clouds accounted for—Colours caused by transmitted Light—Microscopes—Telescopes—Camera-Obscura—Magic Lanthorn—Phantasmagoria—Multiplying-glass.

YOU are still at a loss to account for the different colours of bodies. They exist only in the rays of light which fall upon them, and are reflected off on all sides: a circumstance which is easily explained, now it is known that light itself is compounded of distinct and separate colours. This cloth we call blue, because it absorbs the other rays, and reflects only those which are blue: and so of any other colour. The whiteness of paper, or of snow, is occasioned by its reflecting the greatest part of all the rays in the same mixed state in which they fall upon it. On the contrary, black is occasioned by the substance absorbing all the rays: or more generally, those bodies which have the property of reflecting only the red rays will appear red, those which reflect the greens, blue, &c. will appear green, blue, &c. White is a compound of all the seven primary colours; and black is an entire deprivation of them all; and those which reflect some rays of one colour and some of ano-

ther will be the intermediate shade or colour between both.

To prove that colour is not inherent in bodies, but in the light itself, it can be shewn, that no object whatever can reflect any other kind of light than that which is thrown upon it. If this red ribbon be placed in a violet ray, it will instantly appear of a purple hue, which is a mixture of the red and violet. No art can alter the separated ray; it gives its tint to every object, but will assume none from any: neither reflection nor refraction, nor any other means, can make it forego its natural hue.

Since the red rays are found to have the greatest effect upon the human eye, it has been supposed that they are largest; and that those which least affect the vision are the smallest: these are the violet and the green, which are most agreeable to the eye, and with which we are most conversant, in the clouds above and the grass beneath.

Without light there would be no colours, and the diamond would lose its brilliancy: the vegetable and animal tribes depend upon light for their colours and their existence. Close wooded trees, as the cedar, the yew, the cypress, &c. have leaves only on the outside, the inner parts are almost entirely barren of leaves.—Green-house plants turn their flowers to the light, and if the light be excluded from them, they sicken and shortly die.

Some flowers, as the heart's ease, have their flowers of different colours, even on the same petals; but if these are examined with a microscope, the parts which differ in colour will be found to differ in texture also.

The texture of the petals of the white and red rose is also different.

The colours of natural bodies then are produced by the disposition which they have to reflect one kind of rays more copiously than another. Of course, if light were homogeneous, that is, if it consisted of only one sort of rays, there could be but one colour in the world, and no reflections nor refractions could produce another. According to this theory, which is unquestionably accurate, the ruby absorbs the other colours, and reflects the red: whereas the amethyst in the mineral, and the violet in the vegetable kingdom, absorb the red, yellow, &c. and reflect the milder brightness of the violet. Hence, every coloured object, as we naturally call them, may be considered as separating from light one or more colours, and absorbing the rest.

Those surfaces of transparent bodies which have the greatest refracting power, reflect the greatest quantity of light: thus diamonds, which refract the light very strongly, afford a stronger reflection, and hence proceed the vivacity of their colours, and their brilliant lustre.

I may observe to you, that almost all bodies when reduced to great thinness, are, in a measure, transparent, and the opacity arises from the number of reflections caused in their internal parts. Take, as an instance, the hair of your head, which in the mass is perfectly opake; but view a single hair by means of the microscope, and you will see it is nearly transparent. Gold, which is the heaviest and most dense of all the metals except platina, when beat into thin leaves, will admit the rays of light to pass through them.

Many opake bodies become transparent by filling up the pores with any substance of nearly the same density with their parts. Thus when paper is wet with oil or water, or when linen cloth is varnished, they become more transparent than they were before. On the other hand, separating the parts of a transparent body renders it opake. The most transparent glass, reduced to powder, becomes opake; the same thing happens to horn on its being scraped and made thinner; to water reduced to the shape of steam; and to many other substances treated in the same manner.

Water mixed with air, by being shaken so as to become froth, though both substances were originally transparent, is now opake. But metals, dissolved in acids, give perfectly transparent results: thus solutions of gold in nitro-muriatic acid, and silver in nitric acid, are transparent.

It is supposed, that the transparent parts or particles of bodies, according to their several sizes, must reflect rays of one colour, and transmit those of others in the same manner as thin plates, or soap-bubbles, reflect or transmit these rays, which is the cause of all their colours. On this principle is explained the variety of colours seen in some silks and stuffs, and in the finely coloured feathers of the peacock, and other birds: likewise those of the cameleon, the skin of which is transparent, and the animal, being endowed with the faculty of blowing up or contracting its skin at pleasure, causes the colours to vary.

In the passage of light through the atmosphere, the fainter coloured rays are stopped in their passage through

the atmosphere, and thence reflected upon other bodies; while the red and orange rays are transmitted to greater distances, which accounts for the blue colour of the sky, and the red colour of the clouds, when the sun is near the horizon.

Mr. Delaval, who gave an account in the Manchester Transactions of many experiments made to ascertain the manner in which colours are produced, maintains, that they are exhibited by transmitted light alone, and not by reflected light. He contends, that the original fibres of all substances, when cleared of heterogeneous matters, are perfectly white, and that the rays of light are reflected from these white particles through the colouring matter with which they are covered, and that this colouring matter serves to intercept certain rays in their passage through it, while a free passage being left to others, they will exhibit according to these circumstances, different colours. As an instance, he says, the red colour of the shells of lobsters, after boiling, is only a superficial covering spread over the white calcareous earth of which the shells are composed, and may be removed by scraping or filing. Before they are boiled, this covering is so thick as to admit the passage of light to the shell and back again; but where this transparent blue colour of the unboiled lobster is thinner, it constantly appears like a blue film. In the same manner, the colours of the eggs of certain birds are entirely superficial, and may be scraped off, leaving the white calcareous earth exposed to view. The case is the same with feathers, which owe their colours wholly to a very thin layer of some transparent matter upon a white

ground; this was ascertained by scraping off the superficial colours from certain feathers, which separated the coloured layers from the white ground on which they have been naturally spread.

Having, my young friend, had occasion to allude to the microscope, I will now give a description of that instrument, and shew you its construction. Microscopes are intended for viewing small objects, which the eye without such assistance could not see, either at all, or at least not distinctly.

We cannot see small objects at a nearer distance than about six inches, and it is to enable us to look at them much nearer than this, that we make use of glasses, because the apparent magnitude of objects is measured by the angle under which they are seen by the eye, and these angles are greater or less according as the same or equal objects are nearer to, or farther from the eye.

EXPERIMENT I. Suppose *x* and *z*, fig. 22, to be two equal objects, one at the distance of six or seven inches from the eye E, which is the distance of distinct vision, and the other at half that distance; to enable the eye to see the object *x*, a lens must be interposed somewhere between *x* and E, which is to cause the rays that proceed from the object to go out of the lens parallel to one another, and by this means they will be converged to a focus on the retina.

EX. II. Take a single point of the object (since what is shewn with regard to one point holds good in all, for every point of an object to be visible, must be brought to a focus on the retina), the point *x*, fig. 23, being near the eye, will throw out its rays too divergent to admit of

distinct vision: to remedy this, a lens *l*, fig. 24, is interposed, so as the object *x* may be in the focus of it, which causes the rays to go out parallel to one another, and the object is distinctly painted on the retina; of course it appears as much larger at *x* than at *z*, as the angle *a* E *b* is greater than *m* E *n*, fig. 22.

Since then convex lenses render objects distinctly visible to the eye at the distance of their foci, they become of themselves microscopes.

Ex. III. If the distance *x*, fig. 23, be 7 inches from the eye, where it is seen distinctly, and the focal distance of the lens *l*, be $\frac{1}{2}$ an inch, then since *l x* is only $\frac{1}{14}$ of E *x*; the length of the object at *x*, fig. 24, will appear 14 times as large as it would at *x*, fig. 23, without a lens; and the surfaces of bodies being as the squares of their diameters, or in this case as the squares of their lengths, the surface of *x*, in fig. 24, would appear $14 \times 14 = 196$ times larger than at *x*, fig. 23, where no lens is interposed.

In some small lenses the focal distance is not more than $\frac{1}{4}$ or the $\frac{1}{10}$ of an inch; then, in the same example, the length would be magnified 28 or 70 times, and the surface $28 \times 28 = 784$ or $70 \times 70 = 4900$ times.

You will perhaps ask, whether the lens does not actually magnify the object; it is a natural question, and my reply is, that the increase of size regards the *apparent* not the real magnitude of objects. They appear larger with, than without the lens, but that is because the eye is enabled to see them at a much smaller distance.

Ex. IV. Bring your eye to within a couple of inches of the letter you are reading, and you cannot possibly

make out a single letter; but at the same distance look at it through a small hole, made with a needle or pin, in a sheet of brown paper, and you can read very readily all that I have written. The hole in the paper cannot increase the size of the letters, but it only enables you to see at a shorter distance than you could without it; so it is with the lens; and whatever instrument or contrivance can render minute objects visible and distinct is a microscope.

Ex. v. There are three kinds of microscopes: the single, the compound, and the solar.

The single microscope is nothing more than a double convex lens, such as I have already described, having the object in one focus, and the eye at the same distance on the other side. The magnifying power of this is found by dividing 6 or 7 inches, according as the eye sees best at the one distance or the other, by the focal distance of the lens. To you, who are short sighted, a lens will not magnify so much as it does to me; for if its focal distance be the $\frac{1}{10}$th of an inch, to you it will magnify 60 times; and to me, who can see better at 7 inches than at 6, it will magnify 70 times, and the surfaces will be magnified to you $60 \times 60 = 3600$ times, to me $70 \times 70 = 4900$ lines.

Ex. vi. The compound microscope consists of an object-glass, and an eye-glass, a section of one with a section of the human eye, are given in fig. 25, it consists of the object-glass *c d*, and the eye-glass *e f*; the object to be viewed, is *a b*, which is placed rather beyond the focus of the glass *c d*, so that the pencils of rays flowing from the different points of the object, and

passing through the glass, may be made to converge and unite in as many points between *g* and *h*, where, if a paper were placed, it would be found that an inverted image is formed; which image, and not the object, is viewed by means of the eye-glass *e f*. The image *g h* is in the focus of *f c*, and the eye is about the same distance on the other side of the lens; so that the rays at *e f* going out parallel (see fig. 6.) will continue so, till they come to the eye at *k*, where they will be converged by the refractive powers of the crystalline and other humours, and crossing each other in the pupil they will be collected into points on the retina, and form the large image A B upon it, which will be erect with regard to the object, and of course will appear to be inverted.

The magnifying power of the compound microscope is in proportion as the image *g h*, is larger than the object *a b*, and likewise in proportion as we are able to view it at a less distance. If *g h* be 5 times larger than *a b*, and by the help of the eye-glass *e f*, we can see 12 times nearer than we could by the naked eye, then the length of the object will be apparently magnified 60 times, and the surface 3600 times.

Ex. VII. Sometimes there are two eye-glasses, to enable the observer to have a better view of the object, though one not so much magnified. A microscope fitted up, is represented by fig. 26, the object is placed on the brass stage F, in which is a small hole to admit upon it a strong light from the speculum H; at Q is the object-glass by which the magnified image is made as at *g h*, in fig. 25; at B is a large lens, to increase the field of view;

and at A is an eye-glass, in the focus of which is the enlarged image of the object.

Ex. VIII. The solar microscope can be used only when the sun shines strongly; it is composed of a tube, a plane mirror A B, fig. 27, the lens *x* in the shutter *d z*, and another lens *a* in the tube; the mirror receives the sun's rays, *s s*, and is so placed as to reflect them through the lens *x*; these illuminate the object *c g*, which object is placed in the focus of the lens *a*, here the rays from the object cross and diverge to a white screen or table-cloth, &c. on which the image of the object is painted. The magnifying power of this instrument depends on the distance of the screen from the window; eight or nine feet give a good distance, and the size of the image is to that of the object, as the distance of the former from the lens *a*, to that of the latter.

Telescopes are optical instruments used for viewing objects at a great distance: of these there are two kinds, viz. the "refracting," and the "reflecting."

Ex IX. The common refracting telescope consists of an object-glass, and an eye-glass of course; on the same principle as that of the compound microscope, it inverts the image with respect to the object, and is unfit for viewing terrestrial objects. Fig. 28, is the representation of the section of such a telescope, *x y* is the object, the image of which is, by means of the lens *o p*, formed at *m d*; this is the focus of the eye-glass *g h*; therefore, the rays of each pencil, after passing through the glass, will be parallel, but the pencils will cross at the focus on the other side, as at *e*, and the pupil of the eye being in this focus, the image will be viewed under the

angle *g e h*, and being at E, it will appear magnified, so as to fill the space C D.

The magnifying power of this telescope is found by dividing the focal distance of the object-glass by the focal distance of the eye-glass: thus, if the focal distance of the object-glass be 120 inches, and it admit of an eye-glass whose focal distance is $2\frac{1}{2}$ inches, or 2.5; the former 120 divided by 2.5, gives 48 for the number of times that such a telescope will magnify the diameter of an object.

Ex. x. To shew terrestrial objects erect, the telescope must have one object-glass, *c d*, fig. 29, and three eye-glasses, *e f*, *g h*, *i k*. Here the pencils of rays flowing from A B, pass through the lens *c d*, and form the image C D at F, which is the focus of the lens *e f*, from whence they pass on to the next glass *g h*, and in passing it they are converged to the points in its other focus where they form an erect image, E F, at *m*, and as this is in the focus of the eye-glass *i k*, and as the eye is at the same distance on the other side, the image is viewed through the eye-glass as in the other, only in a contrary position. The three eye glasses have all their focal distances equal, and therefore, the magnifying power is found by dividing the focal distance of the object-glass by the focal distance of either of the eye-glasses.

The reflecting telescope is thus described: let *a b*, fig. 30, be a distant object; parallel rays issuing from it, will be reflected from the concave mirror *c d* to its focus *m*, at *s t*, where the image is formed; there they cross and pass on to the small mirror *e n*, from which they are reflected through the hole o in the large mirror, to B,

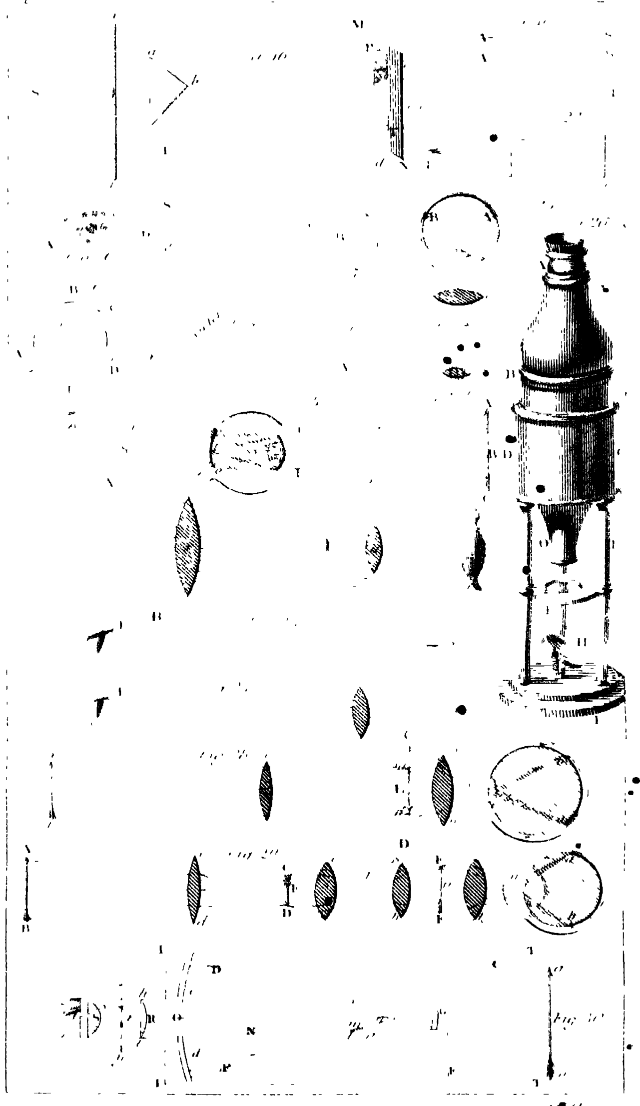
where there is a plano-convex lens, which causes them to form an erect image at *r*, which is magnified by the lens s, and is seen by the eye as large as *z y*. You will remember that the hole o in the large mirror does not in the least distort the image, but is only the cause of the loss of a little light.

There are various constructions of the reflecting telescope; but from what has been said you will easily understand the general principles on which they are formed.

I will mention another instrument or two; the "camera obscura" is made by fixing a convex glass in a hole of the shutter, and if no light enters the room but through the glass, the pictures of all objects on the outside may be seen in an inverted position, on a white paper placed in the focus of the lens.

The construction of the "magic lanthorn" is very simple, consisting only of a tin lanthorn, within which is a lamp whose light passes through a great plano-convex lens, placed in a tube fixed in the front. This strongly illuminates the small transparent painting on glass placed before the lens in an inverted position: another tube, containing a convex lens, slides within the other so as to adjust the focal distances of the glasses.

The exhibition of the "phantasmagoria" which excited so much attention and surprise a few years since, is a "magic lanthorn" of a peculiar construction. In the common lanthorns, the figures are painted on glass, and the rest of the glass is transparent; of course the image on the screen is a circle of light having a figure on it. In the phantasmagoria the whole of the glass is opake except the figure, which being painted in transparent co-



lours, the light shines through it, and as no light can come upon the screen, but what passes through the figure itself, we have on the screen a figure only without any circle of light. The representation is thrown on a thin screen of silk, placed between the lanthorn and the spectator. By moving the lanthorn farther from the screen, or by bringing it nearer to it, the image appears to approach or recede. The size of the image increases as the lanthorn is carried back, because the rays come in the form of a cone; and as no part of the screen can be seen, the figure appears to be formed in the air, and to move farther off when it becomes smaller, and to approach as it increases in size, though in truth it is always at the same distance.

The principle of the multiplying glass is this: the glass is originally a double convex lens, and the sides instead of being left convex, are cut into a number of flat surfaces, and as rays of light proceed from objects in all manner of directions, some will fall on every surface of the glass, and a distinct picture of the object will be seen through each of them; therefore, by increasing the number of surfaces we have the greater number of pictures of any object at which we direct the glass. The object will not appear magnified, but as rays flow from it to all parts of the glass, and each plane surface will refract these rays to the eye, the same object will appear to the eye in the direction of the rays, which enter it through each surface.

ASTRONOMY.

LETTER XXIV.

The importance of Astronomy— Common appearances—Magnitudes of the heavenly Bodies—Planets—Fixed Stars—Comets—Fixed Stars, how divided—Constellations—Distances of the fixed Stars, nebulæ, &c.

ASTRONOMY, my young friend, is one of the most interesting, as well as most important sciences which can occupy the human attention. It presents to us a long series of discoveries, almost from the commencement of time to the present day. Though you cannot look back so far, yet it is less than 40 years since a planet, with its attendant moons, unknown to the inhabitants of the earth, from its creation, was discovered by the celebrated Herschel. And the present century, though so recent, has presented us with four other planetary bodies, different indeed from the other planets in their magnitudes, but in many respects bearing a strict analogy with them.

The world, according to the opinion of unlettered and unthinking men, is composed of two principal parts, the earth and the sky. To them the earth appears as a vast flat surface extending itself circularly on all sides: when a person changes place upon this surface, he loses

sight of certain countries, and discovers others, yet he always considers himself at the centre of the extent presented to him. The sky seems as a vast canopy spangled with the sun, moon, and stars, placed to minister to his enjoyment, and that of his fellow mortals.

The apparent motion of the sun and stars is obvious to the most inconsiderate, and the mass of the people never think of enquiring into the causes. In the morning, they see the sun rise in the east, and behold him traverse, in the course of the day, the vault of the heavens, and then as regularly set or disappear in the evening in the west. These circumstances, so important to the happiness and well-being of man, are overlooked, because they are common. But if it were possible for a being possessed of reason and understanding to behold the phenomena for the first time in his existence, what what would be his joy at the appearance of that luminary which brings light and life in his train; and how gloomy must be his sensations when he saw it apparently take its leave for ever. We cannot enter into the feelings which such a situation would infallibly produce. From our infancy we are accustomed to behold alternate light and darkness, and expecting the one to succeed the other, it occasions no surprise, and too frequently, no gratitude to the Being who has appointed them, for the wisest and most beneficial purposes.

If in a fine clear night, and on an eminence where the view is uninterrupted, we follow with attention, the appearance of the heavens, it will be seen to vary at almost every instant. Some stars are rising, in the eastern part of the heavens, into our sight, others on

the opposite side are sinking into shade: some which now appear just over our heads, decline towards the west, and others mount to their places. Some, indeed, and these very remarkable stars, and constellations of stars, never disappear, never sink, as others apparently do, into the western ocean: of these we may reckon the pole star, and those known by the name of Charles's wain, or the ursus major, or great bear. Thus the whole heavens appear to revolve about two fixed points, called from this circumstance, the *poles* of the world: one of these is ever elevated above our horizon, and the other is perpetually below it. These appearances, which are obvious to all who are blessed with eyes to witness the wonders of creation, excite several interesting enquiries. What becomes during the day of the stars, which we have seen at night? Whence do those come which begin to appear? Where are those gone which have left our view? There are other questions of similar import, which it will be my business in this and some following letters to answer, I hope, to your satisfaction.

Your own observations will go to resolve some seeming difficulties. In the morning, the brilliancy of the starry firmament grows fainter as the dawning light increases: in the evening, the splendour gradually increases as the twilight diminishes: it is not, therefore, as you may infer, because they cease to shine, but because their light is effaced by the more vivid light of the sun, that we are unable to see them. The telescope proves this beyond all doubt, for with that instrument the stars are visible even when the sun shines the brightest, and those which are near enough the poles

never to reach the horizon, appear constantly above it.

The sun and moon appear to us larger than the other heavenly bodies, but we cannot, from their apparent magnitudes, infer what is their real size. The apparent diameters of these bodies are easily obtained by means of good instruments; and if by any means we can come at their distances, we have then sufficient data to find their relative magnitudes. This is applicable to the sun, moon, and planets; but no method yet has been discovered by which we may appreciate the magnitudes and distances of the other stars. These appear only as brilliant points in the heavens; but perpetually retaining the same mutual position with respect to one another, and rising and setting at the same points of the horizon, they are denominated *fixed* stars, in opposition to the others, which are continually changing their place in the heavens, and which are on that account called planets or wanderers. Observe the moon, for instance, or Venus, when she is visible, for a few successive evenings, and you will find it never rises twice at the same point of the horizon, and a few days will make a material difference; but the same observation extended to Arcturus, or Sirius, or any other well known permanent star, will give you clear and distinct ideas of the difference between planets and fixed stars.

Besides the planets and fixed stars, there are occasionally seen in the heavens other luminous bodies, which are usually attended with a kind of tail, or as if they were surrounded with hair; hence they are denominated comets, or hairy stars, from the Latin word *coma*;

hair. The motions of these bodies, and their orbits, that is, the paths in which they travel, are different from those of the planets, and therefore it is always difficult, and frequently impossible, to calculate the periods of their return; whereas we can ascertain the periodical revolutions of Jupiter, Mars, &c. with as much precision as we calculate upon the return of day-light and darkness among ourselves.

Planets and comets are not merely distinguished from the other stars by their motions, but they differ as much in their light, which is more steady, and less subject to that tremulous appearance, which we denominate twinkling.

The fixed stars undoubtedly shine by their own light, but the planets, their moons, and the comets, shine by light borrowed from the sun. When seen through a telescope which magnifies considerably, they appear with well-defined circular disks.—This is not the case with the fixed stars, which, however magnified, appear merely like luminous points. Both the planets and fixed stars differ much in colour from one another. The twinkling of the fixed stars is generally referred to changes which are perpetually taking place in the atmosphere through which their light passes to us. Of their actual magnitude, as we have observed, we can give no account; but in common language, they are divided into seven orders, according to the degrees of their apparent brightness; we call the brightest, stars of the first magnitude, and those that are the least bright, and most difficult to be distinguished by the naked eye, are stars of the sixth magnitude. Those of the seventh are visible only with

an instrument, and are called telescopic stars. Philosophers, not being able to ascertain the distances of the fixed stars, have not been deficient in conjectures, and upon apparently rational grounds, they suppose the nearest fixed star must be a hundred million millions of miles from us; and they infer that the diversity of their apparent magnitudes is principally owing to their different distances.

EXPERIMENT. The light of stars of different magnitudes, situated near each other, may be compared by viewing them through two apertures of different sizes, cut in cards, one held before each eye—the apertures being reduced to such magnitudes, that the stars may appear equally bright. See Dr. Young's Lectures, vol. i. p. 492.

The ancients divided the starry sphere into particular constellations, or systems of stars, according as they lay near each other, so as to occupy those spaces which the figures of different sorts of animals or things would take up if they were there delineated. This is a convenient method for distinguishing them from one another; so that any particular star may be readily found in the heavens by means of a celestial globe, on which the constellations are so delineated as to put the most remarkable stars into such parts of the figures as are most easily distinguished. You may turn to your globe, and you will observe there are about seventy constellations marked on its surface—though the ancients counted only fifty. I will, at the end of my letter, put down their names and the number of the stars noticed in each, by Ptolemy, who was one of the first observers, and by

Flamsteed, who was one of the latest. You will see also on your globe, that there are certain Greek letters marked against the stars, the first of which in the several constellations in the alphabet is always put to the stars of the first magnitude, the second to the next, and so on; by this method, which was invented by Bayer, a German astronomer, more than 200 years ago, the stars are as easily distinguished as if each had an appropriate name. Thus, if I were to ask you to find β, γ, or δ of the constellation Leo, you would point them out as readily on the globe, and after that in the heavens, as you could the constellations themselves.

The heavens are also divided into three parts, viz. into the zodiac, and the parts on each side of it, north and south. The zodiac goes quite round the heavens, and is about sixteen degrees broad; it is denominated zodiac from a Greek work signifying animal, because most of the constellations in it have the names of animals: they are ARIES, the ram: TAURUS, the bull: GEMINI, the twins: CANCER, the crab: LEO, the lion: VIRGO, the virgin: LIBRA, the balance: SCORPIO, the scorpion: SAGITTARIUS, the archer: CAPRICORNUS, the goat: AQUARIUS, the water-bearer: and PISCES, the fishes.

Within the zodiac the orbits of the moon and planets are situated; and along the middle of it is the ecliptic, or that circle which the earth actually describes, and which the sun, to us, appears to describe.

Besides the constellations, there are some single stars, and small collections of stars, that have particular names; such is the bright star in the breast of the lion, called cor Leonis, or the lion's heart; a large star be-

tween the knees of Bootes, is called Arcturus; the cluster of small stars in the neck of the bull is called the "Pleiades;" and the five stars in the bull's face, the "Hyades."

Some of the stars are found by a good telescope to be much nearer together than the rest, so as to form what is denominated a nebula. The ancients had noticed a few of the most conspicuous nebulæ; but Huygens, whose name you will often meet with in connection with the sciences, first directed the attention of modern astronomers to the large nebula situated in the constellation of Orion. Dr. Herschel, in more recent times, has composed a catalogue of 2500 nebulæ. Perhaps all stars are disposed in nebulæ, and those which appear to us to be more widely separated, are individual stars of that particular nebula in which we are placed, and of which the most distant parts may be observed in the form of a lucid zone, called the milky-way, being too distant to allow its single constituent stars to be perceived by the naked eye. Supposing all the stars in this nebula to be as remote from each other as the nearest of them are from the sun—and it has been calculated that the most distant must be 500 times as far from us as the nearest—and that light which is probably 15 or 20 years in travelling to us from Sirius, would be 10,000 years in coming to us from the boundary of the milky-way. It has likewise been calculated that a nebula of the same size as this to which we are supposed to belong, and that should appear only a diffused light, of a degree in diameter, must be at such a distance that its

light, travelling at the rate of 200,000 miles in a second, would require a million of years to reach us.

I must tell you, that the fixed stars are now found to be not absolutely immoveable with respect to one another: for it has been proved that Arcturus and others have progressive motions, amounting to two seconds or more annually: but the distances of these stars being so great, it is almost impossible, but by the nicest and long continued observations, to detect the motions, though they may actually revolve about one another. It is time, however, that I put an end to this letter, which I will with giving you a table, as I promised, containing the names of the constellations, and the number of stars observed in each by Ptolemy and Flamsteed.

TABLE.

The Ancient Constellations.		*Ptolemy.*	*Flamsteed.*
Ursa Minor	The Little Bear	8	24
Ursa Major	The Great Bear	35	37
Draco	The Dragon	31	80
Cepheus	Cepheus	13	35
Bootes, *Arctophilax*	Bootes	23	54
Corona Borealis	The Northern Crown	8	21
Hercules, *Engonasin*	Hercules kneeling	29	113
Lyra	The Harp	10	21
Cygnus, *Gallina*	The Swan	19	81
Cassiopeia	The Lady in her Chair	13	55
Perseus	Perseus	29	59
Auriga	The Waggoner	14	66
Serpentarius, *Ophiuchus*	Serpentarius	29	74
Serpens	The Serpent	18	64
Sagitta	The Arrow	5	18
Aquila, *Vultur* Antinous	The Eagle Antinous	15	71

The Ancient Constellations.		*Ptolemy.*	*Flamsteed.*
Delphinus	The Dolphin	10	18
Equuleus, *Equi sectio*	The Horse's Head	4	10
Pegasus, *Equus*	The Flying Horse	20	89
Andromeda	Andromeda	23	66
Triangulum	The Triangle	4	16
Aries	The Ram	18	66
Taurus	The Bull	44	141
Gemini	The Twins	25	85
Cancer	The Crab	23	83
Leo	The Lion	35	95
Coma Berenices	Berenice's Hair		43
Virgo	The Virgin	32	110
Libra, *Chelæ*	The Scales	17	51
Scorpius	The Scorpion	24	44
Sagittarius	The Archer	31	69
Capricornus	The Goat	28	51
Aquarius	The Water-bearer	45	108
Pisces	The Fishes	38	113
Cetus	The Whale	22	97
Orion	Orion	38	78
Eridanus, *Fluvius*	Eridanus, *the River*	34	84
Lepus	The Hare	12	19
Canis major	The Great Dog	29	31
Canis minor	The Little Dog	2	14
Argo Navis	The Ship	45	64
Hydra	The Hydra	27	60
Crater	The Cup	7	31
Corvus	The Crow	7	9
Centaurus	The Centaur	37	35
Lupus	The Wolf	19	24
Ara	The Altar	7	9
Corona Australis	The Southern Crown	13	12
Pisces Australis	The Southern Fish	18	24

The new Southern Constellations.		*Flamsteed.*
Columba Noachi	Noah's Dove	10
Robur Carolinum	The Royal Oak	12

The new Southern Constellations.		Flamsteed
Grus	The Crane	13
Phœnix	The Phœnix	13
Indus	The Indian	12
Pavo	The Peacock	14
Apus, *Avis Indica*	The Bird of Paradise	11
Apis, *Musca*	The Bee or Fly	4
Chamæleon	The Cameleon	10
Triangulum Austiale	The South Triangle	5
Piscis volans *Passer*	The Flying Fish	8
Dorado, *Xiphias*	The Sword Fish	6
Toacan	The American Goose	9
Hydrus	The Water Snake	10

Hevelius's Constellations made out of the unformed Stars.

		Hevelius.	*Flamsteed.*
Lynx	The Lynx	19	14
Leo minor	The Little Lion		53
Asterion and Chara	The Greyhound	23	25
Cerberus	Cerberus	4	
Vulpecula and Anser	The Fox and Goose	27	35
Scutum Sobieski	Sobieski's Shield	7	
Lacerta	The Lizard	10	16
Camelopardalus	The Camelopard	32	58
Monoceros	The Unicorn	19	31
Sextans	The Sextant	11	41

LETTER XXV.

Solar System—Pythagorean System of the World—Ptolemaic and Tychonic Theories—Copernican System—Primary Planets—Secondary Planets—Description of an Ellipse—Centrifugal and Centripetal forces—Distances of the Planets—Table of the Solar System.

THE sun, my young friend, is to other worlds what one of the fixed stars is to us; they agree in the properties of constantly emitting light and of perpetually retaining their relative situations, at least with but little variation, with respect to the other fixed stars, and it is highly probable that they have many other properties in common. The sun then may be regarded as a fixed star, comparatively near to us, and the stars are to be considered as suns to other systems of worlds perpetually revolving about them, as we shall now shew that the earth and other planets are turning about the sun.

To us, the sun is the most conspicuous of all the celestial bodies; at which you will not be surprized, when you consider how much is dependant upon him. On his attractive power the earth and planets depend for that circular kind of motion, which carries them round him in their several years or periodical revolutions: on him they depend for the blessings of light and heat, which are distributed in greater or less proportions, according to their relative distances from that body. While, however, we reflect on the advantages derived

from the power and attractive influence of the sun, we must not forget that infinite *power* which created the sun; that *wisdom* which adjusted all the proportions so accurately as to enable this great luminary to retain the planets in their orbits: and that *goodness* which no doubt in other planets, and other worlds has adapted the quantities of light and heat to the wants of their inhabitants.

You know, because it is a species of knowledge which we obtain at an early period of our existence, that the "Solar System" consists of the sun and several planets, together with their moons and comets. Various opinions have been adopted by philosophers, with respect to the motion of the sun and planets. The uninformed of all countries and all ages, trouble themselves but little about the appearances of nature what they see, or think they see, they give credit to; and hence they infer, that the earth is an immoveable extended plane, round which the sun and stars perform a revolution every twenty-four hours. Such, probably, was the general opinion in the early ages of the world; nor can we trace the beginnings of science so completely, as to know when other and more rational doctrines were taught. It is, however, believed upon pretty good evidence, that Pythagoras, who flourished five centuries before the Christian æra, was acquainted with the true system of the world; but whether he was the author of the system, or an improver only upon other men's discoveries, cannot be ascertained. He contended that the planets revolved about the sun as a common centre; he taught that the moon reflected the rays of the sun, in other words, that the moon shone by

a borrowed light; he contended that the stars were worlds, and that the moon was inhabited like the earth, and that the comets were a kind of wandering stars, disappearing in the farthest parts of their orbits, and becoming visible as they approached the sun. The white colour of the milky-way he ascribed to the brightness of a great multitude of small stars; he supposed the distances of the moon and planets from the sun, were in certain harmonic proportions to one another, corresponding to the musical intervals or divisions of the monochord.

How the truths, promulgated at this period of the world, were again lost and forgotten cannot well be conceived; the fact is, however, certain; so that, in the time of Ptolemy, who flourished in the first and second centuries of the christian æra, and who was a most able astronomer, there was not a trace of the Pythagorean system left. This philosopher, guided by the sensible appearances of the heavenly bodies, without regard to their absolute or relative motion, considered the earth as stationary, fixed in the centre of the system, and that the sun and planets were subordinate, and revolved round the earth in 24 hours. This, from its founder, was called the "Ptolemaic system."

Another celebrated system was that invented by Tycho Brahe, a learned Dane; this supposed the earth as the centre of the universe, and the sun constantly going round it; but the other planets were considered as revolving about the sun. In an improvement of the Tychonic system, a diurnal motion was given to the earth about its axis, to account for day and night, instead of forcing the sun and stars to turn round the earth in 24

hours. Those who held this doctrine were called Semi-Tychonics.

To Copernicus, who was born at Thorn, in Prussia, in the year 1472, we are indebted for the restoration of the Pythagorean, or true system of the world. This philosopher was prior, in point of time, to Tycho Brahe, and it is wonderful that a man of such talent and philosophical penetration should have abandoned the theory of Copernicus, to establish one of his own, so full of difficulties, and so little accordant with existing phenomena.

According to the Copernican system, which, in truth, was but a revival of the Pythagorean theory, and which has since been denominated the Newtonian system of the world, on account of the various and highly important discoveries, made by Sir Isaac Newton, in confirmation of the principles adopted by his predecessors, the sun is supposed at rest in the centre, and the earth, and other planets, to move about him in ellipses. Hence the sun and stars are supposed to be at rest, and the diurnal motion which they appear to have from east to west, is occasioned by the earth's rotation from west to east. The sun, according to this theory, is very near the centre of gravity of the whole system, and is the focus of all the planetary orbits.

In the plate which accompanies this (plate 1, Astronomy) you will have a view of the system of the world, according to the Copernican theory, and as it is established at present beyond the possibility of being overturned, because every part of it is now founded on mathematical demonstration, which cannot err.

You know that the planets are distinguished from the fixed stars, by their steady light. Planetary bodies are of three kinds, called primary, secondary, and comets.

There are seven primary planets, beside four very small bodies of the same kind, which have been discovered during the present century. S, in our plate represents the sun, a large body, about a million of times larger than the earth, but the space of a plate is much too diminutive to exhibit either the proportional magnitudes of the sun and planets, or the proportional distances of the planets from the sun. The planet Mercury ☿, is that which is nearest the sun; then comes Venus ♀, that brilliant planet which was formerly denominated Lucifer or Hesperus, according as it was a morning or an evening star; for the ancients had no doubt that these were two distinct stars, till Pythagoras, by exact observation, found that it was the same planet in different positions. Next to Venus is the earth ⊕, with her moon revolving about her; then comes Mars ♂; after which we have the orbits of the four newly discovered, and, to the unassisted eye, invisible planetary bodies, viz. Juno, Pallas, Ceres, and Vesta, marked in the plate J, P, C, and V; beyond these revolves Jupiter ♃, with his four moons; then comes Saturn ♄, with seven moons; and far beyond him is the Herschel planet, with his six moons.

You will observe that Venus and Mercury are called *inferior* planets, because their orbits are included within that of the earth; the others are denominated *superior* planets, as their orbits include that of the earth.

The secondary planets, which are denominated satellites or moons, are attendants on the primary planets, and

revolve about them while they move round the sun. Comets are bodies which likewise revolve about the sun in very eccentric elliptical orbits, such as are described in the plate c, c.

Although the orbits of the planets are drawn as circles in the plate referred to, yet the true orbits, or the paths in which they move about the sun, are not circles but ellipses, such as is represented in figure 1, Plate II. Here A C B D represents the orbit of a planet; S *s* are the two foci, that is, the two points from which the ellipse* would be drawn, and S is supposed to be the place of the sun. A B is called the transverse axis, and C D the conjugate axis of the ellipse: but as an astronomical term, A B is called the line of the Apsides, and when the sun is at S, and the planet at A, its greatest distance from it, the planet is said to be in aphelion, or higher apsis; when it is at B, the other extremity, or nearest the sun, it is then in perihelion, or lower apsis. The mean distance of a planet from the sun at S, is when the planet is at C or D, that is, at either extremity of the conjugate diameter; and this mean distance is equal to half the sum of its greatest and least distance

* An ellipse is a transverse section of a cone formed by a plane cutting both sides of the cone; but the section must not be parallel to the base, because the section of a cone parallel to its base is always a circle, and is greater or less according as it is more or less distant from the apex. To describe an ellipse in an easy manner, let two pins, nails, &c. be stuck into a table, and a thread be tied loosely round them; then let a pencil be held within the thread, kept pretty tight, and moved round the pins, which will describe the ellipse. The points where the pins stick are the foci; and according as those points are nearer to or farther from the centre, the ellipse will have more or less eccentricity; for when they coincide in x the curve is a circle.

from the focus in which the sun is placed, that is, the line $CS = \frac{AS+SB}{2} = \frac{AB}{2}$.

Two planets are said to be in *conjunction* when they are in the same point of the heavens, or answer to the same degree of the ecliptic; suppose Jupiter and Venus to be in the 10th degree of Sagittarius, they are said to be in conjunction; and when two planets are in opposite points in the heavens, they are said to be in *opposition;* if Jupiter be in the 10th degree of Aries, and Saturn in the 10th degree of Libra, they will be in opposition.

Before I conclude this letter, let me impress your mind with the nature of the powers which cause the planets to keep in their course. These are called the *centrifugal* and *centripetal* forces.

A centrifugal force is that by which a body, revolving round a centre, or round another body, endeavours to recede from it.

A centripetal force is that by which a moving body is perpetually urged towards a centre, and made to revolve in a curve.

It is, as you have seen, page 32, an established law of nature, that all motion is of itself rectilinear, and a moving body never recedes from its first right line, till some new impulse be superadded in a different direction; after this new impulse the motion will be rectilinear, though the direction of the line will be altered: plate 2, fig. 1. To move in a curve line, a body must receive a new impulse, in a different direction, every instant of time; now to apply this to the motion of the planets: suppose the earth at A, it has, by the centrifugal force impressed on it by the Deity, a tendency to fly off in

the right line A z, but the centripetal force, occasioned by the attraction of the sun constantly acting upon it, draws the earth towards itself: and, therefore, as there are two contending forces, one in the direction A z, the other in the direction A s, the planet must describe a line between the two; and as the attractive force of the sun is perpetually acting upon it, the planet will describe a curve A C B D, for the same reasoning will apply when the planet is situated in any other part of the ellipse, as at *w*, &c.

The effects of a centrifugal force may be familiarly illustrated by whirling a stone at the end of a string. A hoop driven by a boy, and a bowl urged along a plane, are likewise instances of the centrifugal force.

The general law for ascertaining the distances and velocities of the planets is this: " the squares of the times of the revolution are proportional to the cubes of the distances. If the distances of two planets from the sun be known, and also the time which one of them takes in going round the sun, the time that the other requires is easily found:

EXAMPLE. By the table, p. 235, the distances of the planets Saturn and Herschel are 900 and 1800, that is, 1 to 2, and the periodical revolution of Saturn is known to be about 30 years, therefore to find the period of the Herschel, I say, as $1^3 : 2^3 :: 30^2$
to a fourth proportional, or $1 : 8 :: 900 : 7200$,
but the square root of 7200 is equal to 85, or the number of years that the Herschel takes in circulating about the sun.

The same law is established with respect to the secondary planets, or moons, revolving about their primaries.

TABLE OF THE SOLAR SYSTEM.

	Mean Diameters in English Miles.	Mean Distances from the Sun. (Millions of Miles.)	Rotations about their Axes.			Time of their revolving about the Sun.		
			Days.	*Hours.*	*Min.*	*Days.*	*Hours.*	*Min.*
The Sun	883,246		25	14	8			
Mercury	3,224	37	Unknown.			83	23	16
Venus	7,687	66		23	21	224	16	49
The Earth	7,911	95	1	0	0	365	5	49
The Moon	2,180	95	29	17	44			
Mars	4,189	144		24	39	686	23	30
Jupiter	89,170	490		9	55	4332	14	27
Saturn	79,042	900		10	16	10759	1	51
Herschel	35,112	1800	Unknown.			30737	18	0

LETTER XXVI.

The Sun and its Motions—Dr. Herschel's Theories—Proportional Distances of the Planets—of Mercury—Of Venus.

THE sun is placed nearly in the centre of our system, and revolves on its own axis from west to east in about 25½ of our days. Like many other of the fixed stars, of which the sun is unquestionably one, it has, probably, a progressive motion, at this time, directed towards the constellation Hercules. The direction of the axis of the sun is to a point about half way between the Pole-star and Lyra. The time and direction of the sun's rotation is ascertained by the change of the situation of the spots, which are usually visible, with a good glass, on his disc; these spots were formerly supposed to be elevations or mountains on his surface, but which more modern astronomers think to be excavations in the luminous matter covering the sun's surface. These spots are frequently observed to appear and disappear. Lalande thinks, that they are parts of the solid body of the sun, which, by some agitation of the luminous ocean, are left entirely bare. But Dr. Herschel attributes the spots to the emission of an æriform fluid, not yet in combustion, which displaces the luminous atmosphere, and which is afterwards to serve as fuel for supporting the process; hence he supposes the appearance of many spots to be indicative of the approach of warm seasons.

on the surface of the earth. Many of Dr. Herschel's speculations are curious and important; some of which, taken from the Philosophical Transactions, I will give you in an abridged form, because they not only appear rational, but have a tendency to raise the mind to the most noble contemplations of the works of the Creator.

"Sir Isaac Newton has shewn that the sun, by its attractive power, retains the planets belonging to our system in their orbits; he has likewise pointed out the method whereby the quantity of matter contained in the sun may be accurately determined. Dr. Bradley has assigned the velocity of the solar light with a degree of precision exceeding our utmost expectation. Galileo and others have ascertained the rotation of the sun upon its axis, and determined the position of its equator. By means of the transit of Venus over the disc of the sun, our mathematicians have calculated its distance from the earth;—its real diameter and magnitude;—the density of the matter of which it is composed;—and the laws of the fall of heavy bodies on its surface.

"It is by analogical reasoning that we consider the moon as inhabited. For it is a secondary planet of considerable size, its surface is diversified, like that of the earth, with hills and valleys. Its situation, with respect to the sun, is much like that of the earth; and, by a rotation on its axis, it enjoys an agreeable variety of seasons, and of day and night. To the moon, our globe would appear a capital satellite, undergoing the same changes of illumination as the moon does to the earth. The sun, planets, and the starry constellations of the heavens, will rise and set there as they do here: and

heavy bodies will fall on the moon as they do on the earth. There seems then only to be wanting, in order to complete the analogy, that it should be inhabited like the earth.

"It may be objected, that, in the moon, there are no large seas, and its atmosphere (the existence of which is doubted by many) is extremely rare, and unfit for the purposes of animal life:—that its climates, its seasons, and the length of its days and nights, totally differ from ours;—that without dense clouds, which the moon has not, there can be no rain, perhaps no rivers and lakes.

"In answer to this, it may be observed, that the very difference between the two planets strengthens the argument. We find, even on our own globe, that there is a most striking dissimilarity in the situation of the creatures that live upon it. While man walks on the ground, the birds fly in the air, and the fishes swim in the water. We cannot surely object to the conveniences afforded by the moon, if those that are to inhabit its regions are fitted to their conditions as well as we on this globe of ours. The analogy already mentioned establishes a high probability that the moon is inhabited.

"Suppose, then, an inhabitant of the moon, who has not properly considered such analogical reasonings as might induce him to surmise that our earth is inhabited, were to give it as his opinion, that the use of that great body, which he sees in his neighbourhood, is to carry about his little globe, in order that it may be properly exposed to the light of the sun, so as to enjoy an agreeable and useful variety of illumination, as well as

to give it light by reflection, when direct light cannot be had; should we not condemn his ignorance and want of attention? The earth, it is true, performs those offices which have been named for the inhabitants of the moon, but we know that it also affords magnificent dwelling-places to numberless intelligent beings.

"From experience, therefore, we affirm, that the performance of the most salutary offices to inferior planets, is not inconsistent with the dignity of superior purposes; and, in consequence of such analogical reasonings, assisted by telescopic views, which plainly favour the same opinion, we do not hesitate to admit, that the sun is richly stored with inhabitants.

"This way of considering the sun is of the utmost importance in its consequences. That stars are suns can hardly admit of a doubt. Their immense distance would effectually exclude them from our view, if their light were not of the solar kind. Besides, the analogy may be traced much farther: the sun turns on its axis; so does the star Algol; so do the stars called β Lyræ, δ Cephei, η Antinoi, ο Ceti, and many more, most probably all. Now from what other cause can we, with so much probability, account for their periodical changes? Again, our sun's spots are changeable; so are the spots on the star ο Ceti. But if stars are suns, and suns are habitable, we see at once what an extensive field for animation opens to our view.

"It is true, that analogy may induce us to conclude, that since stars appear to be suns, and suns, according to the common opinion, are bodies that serve to enlighten, warm, and sustain a system of planets, we may have an

idea of numberless globes that serve for the habitation of living creatures. But if these suns themselves are primary planets, we may see some thousands of them with the naked eye, and millions with the help of telescopes; and, at the same time, the same analogical reasoning still remains in full force with regard to the planets which these suns may support." See Phil. Trans. 1796.

The sun is accompanied in his progressive motion among the fixed stars by eleven planetary bodies, which have already been enumerated, revolving around him from west to east in elliptical orbits, approaching nearly to circles, and visible to us by the means of the light which they receive from him. The real distances of the planets have been given in table, p. 235, and to enable you readily to call to your recollection the proportional distances of the primary planets from the sun, you may call the distance of the earth from that body 10, and that of Saturn 100: then the distance of Mercury will be 4, of Venus 7, of the Earth 10, of Mars 16, of Jupiter 52, of Saturn 100, and of the Herschel 196.

The motions of all the planetary bodies, except the four small ones lately discovered, are comprehended in a zone of the celestial sphere called the zodiac, the breadth of which is 18°, and it is divided into two equal parts by the ecliptic. We shall now proceed to these planets.

Mercury, which is nearest the sun, and whose diameter is but about one-third as large as that of the earth, performs his revolutions in less than three months, and at the distance of 37 millions of miles from the sun.

He is rarely seen by the inhabitants of the earth, and then only for a short time. He appears in the evening a little after sun-set, and again in the morning a short time before sun-rise. He is never so much as 28 degrees distant from the sun, and cannot be seen at any one time either before or after the sun, more than about an hour and three quarters. For suppose E A B, fig. 2, the earth's orbit, *m x z* the orbit of Mercury, and s the sun: if the earth be at E and Mercury at *m*, it cannot be seen because of the rays of the sun. As it approaches *x* it becomes visible, and for a short time it will appear as stationary at *x*, it will then be visible till it comes so near *n* as to be hidden by the sun's rays; as, however, it approaches *z* it becomes again visible, and at *z* it appears stationary. In looking at any of the planets, we refer them to the fixed stars, C Z P, and it is evident to you that Mercury, though he makes his circuit in the orbit *x n z m*, will never be seen farther from the place of the sun Z among the fixed stars than O or P, that is, about 28 degrees from Z.

You will also observe, that while Mercury is moving through one part of his orbit as from *x*, through *m* to *z*, it will appear to move in the direction O Z P, but when he comes to the other part of his orbit and moves along *z m* X, he will appear to move among the fixed stars in a contrary order, as in the direction P Z O: this is what is meant by the planet's retrograde motion. You will now know that what is proved of the motions of Mercury is applicable to those of the other planets, and that to an inhabitant on the earth, they may and will appear sometimes stationary, sometimes moving according to the order of the signs, and sometimes in a contrary direction.

You will likewise see the reason why Mercury and Venus can never appear in that side of the heavens which is opposite to the sun, and why they are never seen far from the sun.

The motion of Mercury, thus explained, has been compared to the oscillations of a pendulum swinging backwards and forwards from O to P, and from P to O; and it is found, that though the time of a complete oscillation varies, yet it is never less than 100 days, and never more than 130, and this variation depends on the motion of the earth combined with the motion of Mercury, to which we have not referred.

You will easily conceive, that a considerable time must have elapsed before observers of the heavens could ascertain that the stars which were seen approaching the sun in the evening, and, after a certain interval, were again visible in the morning, were one and the same. The suspicion was probably first excited from the circumstance, of the one never being seen at the same time with the other.

The apparent diameters of Mercury and all the planets vary according to their position with respect to the earth: as they are nearer to or farther from the earth, they appear to us larger or smaller. When the planet Mercury passes from *x* through *n* to *z*, fig. 2, or when its motion is direct, it appears the smallest, because it is farthest from the earth: when its motion is retrograde, or when it moves along *z m x*, it being nearest to the earth, at *m* it will appear largest, and is the largest possible when it plunges in, or emerges from the sun's rays in this part of its orbit.

Sometimes, when Mercury disappears during his re-

trograde motion, that is, when it plunges into the sun's rays in passing through *z m x*, it may be seen crossing the sun under the form of a black spot. This is what is called a "transit of Mercury" over the sun. The transits of Mercury and Venus are really eclipses of the sun, which demonstrate, that the planets are opake bodies, and that they borrow their light from the sun.—Both Mercury and Venus, viewed through a good telescope, exhibit the same phases of horned, gibbous, &c. as the moon. The light and heat enjoyed by Mercury is seven or eight times greater than what we enjoy, and the velocity of his motion is about 105,000 miles in an hour.

Venus, the planet next in order, is the most beautiful star in the heavens, and is commonly known by the name of the morning and evening star. She presents the same phenomena to us as those described of Mercury; but her phases are more sensible, and her oscillations are of longer duration. Since her greatest distance from the sun varies from 45 to 48 degrees, the mean duration of her oscillations is about 584 days. By the transits of this planet in the years 1761 and 1769, the distance of the sun from the earth was accurately ascertained. The variations in the apparent magnitude of Venus are considerable: it seems largest when it passes over the sun, being then the nearest to the earth. She enjoys about twice as much light and heat from the sun as the earth; and she travels in her orbit at the rate of 75,000 miles in an hour.

LETTER XXVII.

Of the Earth—Of the Moon—The Earth a Globe—Diurnal Motion of the Earth—Annual Motion of the Earth—Of the Seasons.

THE earth, my dear sir, is the next to Venus; its diameter is reckoned about 7,911 miles, its distance from the sun is estimated at 95 millions of miles. In passing through its orbit, it travels at the rate of 68,000 miles in an hour, and takes 365 days, 5 hours, 48 minutes, 48 seconds, to make its annual circuit. The earth turns on its axis in about 23 hours 56 minutes, which produces, as you well know, the apparent diurnal motion of the heaverly bodies from east to west in the same time. This diurnal motion of the earth causes likewise what we call the rising and setting of the sun, and the length of the days and nights; for in the morning, that part of the earth on which we live, turns into the light of the sun, and we see it rising, as it were, in the opposite part of the heavens: the farther we move into the light, the more the sun appears to move to us; and in the evening, by our turning from the sun, or sinking below its rays, we conceive the sun to have sunk from our sight.

The axis of the earth is inclined to the plane of its orbit in an angle of about 23½ degrees, and always parallel to itself; that is, the axis as it points to-day, will be parallel to the position it will have a month, or three,

or six months hence, which is the cause of the sun enlightening at one period of the year more of the northern parts of the globe, and at another more of the southern parts: in other words, the inclination of the axis of the earth is the cause of the various seasons of spring, summer, autumn, and winter.

The moon is an attendant on the earth, revolving about it in an elliptical orbit, in one of the foci of which the earth is placed: but as the earth revolves about the sun at the same time that the moon is revolving about the earth, they may both be considered as turning about their common centre of gravity; that is, an imaginary point, which is as much nearer the earth than the moon, as the mass of the earth exceeds that of the moon.

The moon makes its revolution in its orbit round the earth in 27 days 8 hours nearly; moving with a velocity of more than 2,200 miles in an hour. But while the moon has been going round the earth, the earth has moved in its orbit nearly a whole sign, and therefore the time between one new or full moon to another, or when the earth, sun, and moon, will be in one straight line, is 29 days 12 hours nearly. The diameter of the moon is about 2,180, and its mean distance from the earth is 240,000 miles. It is very remarkable, that the time which the moon takes to turn on its axis is precisely equal to the time it takes in making its revolution about the earth: so that its day and night are equal to our lunar month. Another singular circumstance is, that the hemisphere of the moon opposite to the earth is never in darkness; for when it is turned from the sun, it is illuminated by light reflected from the earth in the same

manner as we are enlightened by a full moon. But the opposite hemisphere of the moon has a fortnight's light and darkness by turns, and an inhabitant of that part of the moon would never behold the brilliant light afforded by the earth to his antipodes, unless he travels a thousand or two miles for the sight.

Having given you a general account of the earth and moon, I shall come to some particulars which hitherto I may have seemed to take for granted, but which are easily proved. For instance, we have assumed that the earth is a round body, which is obvious from the following circumstances: (1.) When a ship leaves the shore and goes to sea, a spectator on land first loses sight of the hull, then of the mast, gradually from the bottom to the top: and when a ship approaches land, the top-mast is first visible, and the hull last. See fig. 3. These appearances could not occur if the sea were a plane; because, then every part of the vessel would appear or disappear at the same instant, or rather the hull or body of the ship being so much larger than the mast, would be seen longer than the mast, which is contrary to appearances. (2.) Several of our own countrymen, as Sir Francis Drake, Lord Anson, and Captain Cook, and many others, have actually sailed round the earth, always keeping in the same direction, and yet returning to the ports from which they set out. (3.) The moon is frequently eclipsed by the shadow of the earth, and in all eclipses, the shadow is circular, which is another proof that the earth is a globe, which in all situations projects a conical shadow. (4.) In travelling towards the north, the southern stars are depressed, and the northern stars

elevated : and the sun arrives on the meridian of places that are more easterly sooner than to the meridian of those that are more westerly: that is, it is twelve o'clock at noon, or night, sooner at Rome than at London, and sooner at London than at Lisbon. (5.) The same globular figure is inferred from the operation of levelling, or of conveying water in canals, &c. from one place to another, in which it is found necessary to make an allowance for the difference between the apparent and the real level, or for the figure of the earth.

The real or true level is not a straight line, but a curve which falls below the straight line, or tangent made from any point, about 8 inches in a mile; four times eight, or 32 inches in two miles; nine times eight, or 72 inches in three miles; and sixteen times eight, or 128 inches in four miles, and so on, always increasing as the squares of the distances.

After all, it must be observed, that from actual measurement, it is found that the earth is not a perfect globe, but a spheroid, the diameter of the equator being about 34 miles longer than that between the poles.

Having established the fact that the earth is of a globular form, you will readily believe, that, as the earth must turn on its axis in 24 hours, or the sun and stars turn round the earth in the same time, it is more natural that the motion should be in the earth than the contrary. It will be no argument against it that you cannot perceive the motion: because the motion of a ship in a smooth sea is not observed by the passenger, who would infer, from his sight only, that external objects

were moving from him, rather than that the ship was moving from them. A similar deception is observable in travelling swiftly along a narrow road in a chaise, &c.: or to a person sitting in a windmill while that is turned rapidly round.

Besides, it is known from observing spots on the surfaces of the sun and planets, that they have a motion about their axis, and the earth being a planet, may from analogy be supposed to partake of the same kind of motion. Admitting then the revolution of the earth about its axis from west to east, and the phenomenon of the heavens appearing to turn from east to west is accounted for. As the earth is an opake spherical body at a great distance from the sun, one half of it will always be illuminated, while the other half remains in darkness. The circle which distinguishes the illuminated from the dark side of the earth, and which is the boundary between light and darkness, has been called the terminator: and a line drawn from the centre of the sun to the centre of the earth, is perpendicular to the plane of this circle. Suppose S the sun, (fig. 4.) and D N E S the earth, placed in an inclining position, $x\ d$ represents the terminator, and as the earth turns on its axis, N S part of the dark side is perpetually coming into the light, and part of that which is light is getting into darkness, and when any point in the globe comes into the enlightened hemisphere, the sun is just risen to that part; when it gets half way, or to its greatest distance from the terminator, it is then noon; and when it leaves the enlightened hemisphere it is sunset; and from that time till the sun is 18 degrees beyond the terminator, it is twilight.

The same figure to which I have already referred, represents the annual motion of the earth about the sun; but you will perhaps ask for proof of the fact that the earth does revolve about the sun in a year. In the shaft of a very deep mine, the stars are visible in the day as well as in the night: they may also be seen by means of a telescope fitted up for the purpose. By this method the sun and stars are visible at the same time. Now if the sun be seen in a line with a fixed star, on any particular day, it will in a few weeks be found to the east of him, and by constant observations made at certain intervals, we shall be able to trace him round the heavens to the same fixed star from which we set out, consequently the sun must have made a journey round the earth in that time, or the earth round the sun. But the sun being a million times larger than the earth, it is surely more natural that the earth should have the motion than the sun. Besides, as they must move round a common centre of gravity, the quantities of motion in both bodies must be equal, and the earth being the smaller body, must make up by its motion what it wants in the quantity of matter.

Again, if the sun be regarded as the centre of the planetary system, the bodies all move about it agreeable to the universal laws of gravity, and the motion of the earth round the sun accords with the law of all other moving bodies, viz. " that the squares of the periodical times are as the cubes of the distances." The known facts cannot be accounted for upon any other principle; nor can the motions of Mercury and Venus already described be understood on any other theory.

It may further be observed, that the inhabitants of other planets will consider the existing phenomena as we do: they, if they are ignorant of astronomy, will suppose the sun to move round them in their several years, as the uninformed here suppose he revolves about the earth in 365 days. Thus an inhabitant of Mars would say the sun goes round him in two years: of Jupiter in twelve years: of Saturn in 30 years, and so on. Now, as it is impossible that the sun can have all these motions really in itself, it may be asserted that none of them are real, but that all are apparent only, and arise from the motions of the respective planets.

You may now turn again to fig. 4, which is intended not only to exhibit the annual motion of the earth, but to give you an idea in what manner the seasons are produced. The sun enlightens half the earth, however it is situated. I have drawn you four different positions of the earth, from which you may understand how all the changes are produced. In June, the north pole is in the light, and it is summer to the northern parts of the earth; in December, the south pole is in the light, and it is summer to the southern parts of the globe, and winter to the northern regions. In March and September the sun's light reaches to the north and south poles, because a line drawn from the centre of the sun to that of the earth, will pass through the equator, or through that line which divides the earth into two equal parts; whereas in June such a line would pass higher than the equator *q*, as through *b*, and in September it would pass below it as at *e*: in the former case the sun, to enlighten half the globe, must shine much beyond the pole N, and

not so far as S: and in December the sun will shine much beyond the pole S, and not so far as N.

Hence you see the reason of long days in summer and short ones in winter: for if London or Great Britain be situated at *l*, it is evident that in June almost all the circle on which it stands, is in the light, and in December almost the whole will be in darkness, and in proportion as the circle on which any place is situated is in light or darkness, the length of the day to that place is longer or shorter. Thus, in June the days are 16 hours long in London, and the night only eight; and in December the days are eight hours long and the nights sixteen. While the earth is moving from Libra, through Capricorn to Aries, that is, from March to September; the north pole N being continually in the light, will have six months day: but while the earth is travelling from Aries through Cancer to Libra, the north pole will be in darkness and the south in the light. When the earth is in Aries, or Cancer, we see the sun in the opposite points of the heavens, or in Libra and Capricorn.

You will observe, that the sun is not placed in the centre, but is supposed to be in the focus of the ellipse, the consequence of which is, that the summer season, or the time in which the earth is travelling from Libra to Aries, is about eight days longer than the winter season, or the time in which it is passing from Aries to Libra. You may perhaps inquire why then our winters are so much colder than our summers. The answer is plain; though we are two or three millions of miles nearer the sun in December than in June, yet the weather is hotter in summer than in winter, because the sun

rises so much higher above our horizon in the summer, and therefore its rays fall more perpendicularly on the earth, that is, with more force; and again, because the days are so much longer in the summer than in the winter; by which means the earth and air are heated by the sun in the day, more than they are cooled in the night; on this account, therefore, the heat will keep increasing in the summer, and for the same reason will decrease in winter when the nights are long. The earth being nearer the sun in winter than in summer, causes the diameter of the sun to appear larger in the winter than it is in the summer.

Of the Moon—Phases of the Moon—Eclipses of the Moon—Eclipses of the Sun—Number of Eclipses in a Year—Of the Tides.

THE Moon is a satellite to the Earth, and revolves about it while the Earth is making her journey round the Sun. The Moon's apparent place, viewed by a spectator on the Earth, is extended to a great circle among the fixed stars, and it appears to move through the twelve signs of the Zodiac in a month; that is, in 27 days, 7 hours, 43 minutes; this is called a *periodical* month. The plane of the Moon's orbit intersects the plane of the ecliptic in two points, making an angle with it of about five degrees. The two points where the Moon's orbit cuts the ecliptic, are called the nodes; when the Moon crosses the ecliptic, it is in its nodes, but in all other parts of its orbit, it is above or below the ecliptic; and according as it is north or south, it is said to have north or south latitude.

A synodical month is the time elapsed between one new Moon and the next, which is equal to 29 days, 12 hours, 44 minutes. If the Earth were stationary, the periodical and synodical months would be the same; but as the Earth moves forward in its orbit, while the Moon is performing its revolution, it has not only to pass through its own orbit, but likewise to overtake the Earth again in its passage through the ecliptic: in the

same manner as if the two hands of a watch set out together at twelve o'clock, the minute hand must not only make an entire circle, but part of a second before it overtakes the hour hand.

The Moon is an opaque body, and shines by a light borrowed from the sun, which illuminates one half of its body, and leaves the other in darkness. An inhabitant of the Earth perceives different degrees of this illumination, according to the various positions of the Moon with respect to the Sun and Earth, as is evident from the figure which accompanies this. If K (fig. 5.) be the Earth, and A, B, C, D, &c. the Moon's orbit, then the figures beyond will represent the appearance which the Moon shews to a spectator here, in its several positions. When the Moon is at A, between the Earth and Sun, its dark side will be towards the Earth, and it will be invisible, as it is represented at *a*, and as it really is at change or new-moon. When the Moon is at B, the small part *a x z*, will be seen at K, and its appearance to a spectator there will be such as the light part of *b* shews. In the position *c*, the light part *a x z* is seen at the Earth, under the appearance of the light part in *c*: at D, still more of the illuminated side is turned to the Earth, and at E, the whole enlightened half of the Moon is turned to the Earth, and it appears full-moon, as at *e*. Hence, you see how the Moon waxes and wanes: why it disappears, why it becomes horned, gibbous, &c.

The Earth serves to enlighten the Moon, in the same manner as the Moon enlightens the inhabitants of the Earth; but it appears to the Moon about 13 times larger than the Moon appears to us, and the changes

take place in a contrary order; that is, when the Moon appears full to us, the Earth must be in conjunction with the Sun, and disappear to the Moon. Soon after the new-moon, the whole body is dimly seen, independently of the illuminated crescent, which proceeds from the light that is reflected on it from the Earth: for at our new-moon, the Earth appears as a full-moon to the lunarians, and part of the light which they receive from us, is reflected back again to the Earth.

An eclipse of the Moon is a privation of light caused by the interposition of the Earth between the Sun and Moon which intercepts the Sun's rays, and prevents them from illuminating the surface: you know that every opaque body presented to the light, whether of the Sun, or a candle, projects a shadow behind it. The shadow projected by the Earth is always conical, and when the Moon passes through this shadow, its light is eclipsed. The shadow being conical, it is largest at the base, and runs off to a point; now according to the position of the Earth and Moon, the latter will be sometimes nearer and sometimes farther from the former, and in proportion to its nearness it will have a wider space of shadow to pass through; in other words, the nearer the Moon is to the Earth during an eclipse, the longer the eclipse will last.

The Earth's orbit is in the plane of the ecliptic, when viewed from the Sun, consequently its shadow tends directly to that part of the heavens; and as the Moon's orbit has an inclination of about five degrees with the ecliptic, and only crosses it in two points, called its nodes, the shadow of the Earth cannot fall upon the

Moon, except it is in or near one of its nodes, when the Moon is full, or when it is in opposition. See fig. 6 and 7: in fig. 7, you have a representation of the manner in which an eclipse of the Moon occurs. S is supposed to represent the Sun, M N the Earth, and *m* the Moon in its orbit *o b* just entering, or coming out from the shadow; and you observe how the Moon *m* is situated at the time of an eclipse: the Earth is between it and the illuminating body, the Sun, and so it is every full-moon; but in some cases the Moon passes above, and in some below, the shadow of the Earth, and in either of those situations there will be no eclipse. This is easily proved.

Let a line A D represent a part of the ecliptic, the plane of which coincides with that of the Earth's orbit, and the line C B, part of the orbit of the Moon, crossing the ecliptic at H; and the point H, where they cross, is called the node. Now, if E, F, G, H, represent sections of the Earth's shadow in different positions of its orbit, when the Moon I, approaches its node H, and the shadow of the Earth is at E, there will be no eclipse; but if the Earth's shadow be represented at F, G, H, then the Moon in its passage to B, will just touch the shadow F, it will be totally eclipsed at G, and it will be totally and centrally eclipsed at H. When the Moon is full, it sometimes happens that the Earth's shadow is too low or too high for the Moon to enter in it, as at E; sometimes it is found as at F, or G, or H, and on this depends the nature of the eclipse, or whether there will be an eclipse at all.

The duration of an eclipse depends, as I told you

before, on the length of the shadow it has to pass through, and the duration of a central eclipse, or the time that the Moon takes from entering the shadow at M, till its egress at *m*, is about four hours, during two of which the moon passes through three times the length of its diameter totally eclipsed.

In speaking of eclipses, we suppose the Moon's diameter to be divided into 12 equal parts, called digits; and the magnitude and duration of a partial eclipse are denominated by the number of these digits which are obscured: thus, if a half, or a third, or a fourth of the Moon be obscured, we call it an eclipse of 6, or 4, or 3 digits.

The Earth, like all other opaque globular bodies which receive the Sun's rays, not only throws a dark, converging or conical shadow behind it, but has likewise a thin diverging shadow on each of its sides, as A M B, and A N C, called the penumbra, or almost shadow, which is occasioned by a partial obscuration of light from the Sun.

If S be the Sun, and M N the Earth receiving its rays on its surface, there will be a dark shadow M A N, which cannot receive any of the direct light from the Sun, and a penumbra, or thinner shadow, will fall on each side, more or less dark, according as it is nearer to or further from M A and N C. It is evident that the Moon passes through the penumbra before it enters the dark shadow, and having passed the shadow, it traverses the opposite penumbra before it resumes its usual brightness.

Lunar eclipses are visible over every part of the Earth that has the Moon above the horizon, and the eclipse

appears of the same length and magnitude to all who see it. The eastern side of the Moon enters the western side of the shadow, and passes out at the eastern. You see by the figure, that central eclipses must be the longest; but these are not always of the same length; because the Moon is sometimes in apogee, or the farthest from the Earth; sometimes in perigee, or the nearest to the Earth: sometimes the Earth's distance from the Sun is greater or less, and as it is in aphelion or perihelion; that is, the farthest from, or nearest to the Sun, the duration and quantity of the eclipse will vary. The greatest variation is, however, no more than about 20 minutes, the longest central eclipse being 3 hours, 57 minutes, and the shortest 3 hours, 37 minutes.

The Moon, in an eclipse, has usually a faint copperish appearance, which is attributed to the refraction of the rays of light by the Earth's atmosphere, and which are sent from that to the surface of the Moon.

Eclipses, as you know, depend on the Moon's nodes; now these nodes have a retrograde motion with regard to the signs, and this motion is equal to about $19\frac{1}{3}°$ in a year; so that in 18 years, 225 days, the nodes pass through the 12 signs, and come into the same position again; and this space of time is the period of succession before the same eclipses fall in the same part of the ecliptic.

I will now lead you to the consideration of eclipses of the Sun. What is called an eclipse of the Sun, is caused by the interposition of the Moon between the Sun and the Earth, of which fig. 8 is a representation. Here S is supposed to be the Sun, L the Earth, and M

the Moon, in that part of the orbit which is between the Earth and Sun. Now the dark part, *z s u t*, is the conical shadow projected by the Moon, and this, as the Moon passes by the Earth, will overshadow different parts of the Earth's surface in succession; on each side of the conical shadow is a penumbra; namely, in the spaces *x* t *z*, and *z u s*, because in these spaces there is a partial privation of the rays of the Sun.

As the Moon is so much less than the Earth, it can, as is shewn in the figure, only cover a small part of it by its shadow; therefore to those parts which are out of the shadow, there will be no eclipse, for to them the Sun will appear as usual. The Moon's shadow rarely exceeds 180 miles in diameter, though the penumbra extends much farther both ways. The course of the Moon's shadow on the Earth is generally from west to east, inclining to the north, if it be in the ascending node, and inclining towards the south, if it be in the descending node.

The whole time that the shadow and penumbra take to pass any given point, is called the eclipse; but the total eclipse is only whilst the darkest part passes the place. If the Moon be in its apogee, or greatest distance from the Earth, its shadow is not sufficiently long to reach the Earth, and the Sun appears like a luminous ring round the dark body of the Moon: this is called an annular eclipse.

Professor Vince observes, that the ecliptic limits of the Sun, to those of the Moon, being nearly as 3 to 2, there will be more solar than lunar eclipses in about the same ratio. But more lunar than solar eclipses will be

seen at any given place; because a lunar eclipse is visible to a whole hemisphere of the Earth at once; whereas a solar eclipse is visible to a part only, and therefore there is a greater probability of seeing a lunar than a solar eclipse. Since the Moon is as long above the horizon as below, every spectator may expect to see half the number of lunar eclipses which happen.

An eclipse of the Moon, arising from a real deprivation of light, must appear to begin at the same instant of time to every place on that hemisphere of the Earth which is next the Moon. Hence it affords a ready method of finding the longitudes of places upon the Earth's surface: for, if to a person at Greenwich, the eclipse begins at 10 o'clock, and at other places it is observed to begin at 9 o'clock, or at eleven, then those places will be 15 degrees west and east longitude of London.

The greatest number of eclipses which can happen in a year is seven; and when this occurs, five will be of the Sun, and two of the Moon. The least number will be two; and in this case, they will be both solar: for, in every year there must be two solar eclipses. The mean number in a year is about four. In total eclipses of the Sun, the planets and some stars of the first magnitude have been seen.

There are two seasons in the year when eclipses happen: that is, when the Earth approaches near each node; and as the nodes lie at opposite points of the Earth's orbit, these seasons would be at the distance of half a year from each other, if the nodes were stationary: but, as the nodes have a retrograde motion of about 19

degrees in a year, and as the Earth moves about one degree in a day, the seasons of eclipses will return at an interval of about 9 or 10 days less than half a year: so that if there be eclipses in the middle of April, they may be expected again early in October. Thus, in 1809, there was an eclipse of the Sun, April 14, and one of the Moon, on the 29th; there were also eclipses of the Sun and Moon on the 9th and 23rd of October. In 1808, there were five eclipses; one of the Moon, May 10th, one of the Sun, May 25th; one of the Moon, October 19th, and one of the Sun, November 3rd; and one also of the Sun, November 13th.

Before we leave the astronomy of the Earth, it may be proper to observe, that the tides in rivers, as those in the Thames, and in the sea, are produced chiefly by the attraction of the Moon on the waters, though the attraction of the Sun has some influence on the occasion.

If you look into Moore's Almanac, or into the Ephemeris, you will see that the time of high water is calculated for every day in the year; and it is calculated upon the knowledge of the Moon's and Sun's attractions. At an average, the time of high water varies about three-quarters of an hour on each day: thus, it is high water to-day, the 18th of March, 1821, at 58 minutes past one, and to-morrow it will be 31 minutes past two before it is high water. Sometimes the difference of time is not above half an hour, and at other times it is an hour and a quarter.

You know there is an attraction between all bodies, of course between the Earth and Moon; and when the Moon passes over the sea, it raises the waters, and

causes high tides, not only in that part under the Moon, but in the opposite side of the Earth also.

It is easy to perceive how the attraction of the Moon should occasion a rise of the sea on the side which is turned towards her; but it is not so easy to comprehend how this could take place on the opposite side of the Earth.

To understand this, you must recollect, that from the universal law of gravitation, every particle of the Earth and Moon are drawn towards each other, and that in the inverse proportion of the squares of their distances.

Let *a b c d e f g h* (fig. 1, misc. pl. ii.) represent the Earth, and let the Moon be supposed to be situated in the direction *m m m*. Now the points *a i e* being at nearly the same distance from the Moon, will gravitate alike towards her, in the directions *a m, i m, e m*. Let *a a′, i i′, e e′* represent the degree of force with which they are drawn towards the Moon; but the particles *b* and *d* being nearer to the Moon than *a, i,* and *e,* will gravitate more than them towards her, as by the spaces *b b′, d d′*, and the particle *c*, which is still nearer, will be yet more affected by her influence, and consequently removed to the greater distance *c c′*: hence it is evident, that the semicircular arc, *a b c d e*, will become more and more curved as we approach towards *c*, where it will be most protuberant.—In like manner, the particles *f* and *h*, in the opposite hemisphere, being less drawn from their situations than *a i*, or *e*, are moved over the spaces *f f′*, and *h h′* less than *a a′, i i′*, and *e e′*, and the particle *g*, the most remote, is moved by the least quantity *g g′*, and hence the same effect is produced

in this as in the other hemisphere—an increase of curvature as we approach towards *g*. By this means, the Earth will assume an elliptical form, having the transverse axis in the direction of the attracting force; and thus it is that in every lunar day we have two high tides; the one on the Moon passing our meridian, and the other on her passing the meridian of our antipodes.

The attraction of the Sun, as well as that of the Moon, occasions a variation of tide, but not in so great a degree: this arises from the Sun being at such an immense distance from us, that the gravitation of the particles *a b c d e* towards him, differ less in proportion from each other than the gravitation of those points towards the Moon.

The effect of the Sun, however, upon the tides is very sensible, as may be seen by what are called spring and neap tides; the former are those which take place about the full and new Moon, (which are much the highest, in consequence of the Sun and Moon then acting together), the latter are when the Moon is in quadrature, and are much the lowest, which is occasioned by the Sun and Moon at those times acting in a manner so as to counteract each other.

LETTER XXIX.

Of Mars—Of Pallas, Juno, Ceres, and Vesta—Of Jupiter—Of Saturn—Of the Herschel—Method of measuring the length of a Degree, and finding the Distances of the Earth and Planets from the Sun—Method of finding the Longitude.

I SHALL, my young friend, conclude what I have to say on astronomy in this letter; beginning with the planet Mars, which is next in order to the Earth, and the first of the superior planets. This planet is of a dull reddish colour, and sometimes appears as large as the planet Venus. He is not subject to the same limitation in his apparent motions as Mercury and Venus, but sometimes appears to be near the Sun, and sometimes in the opposite part of the heavens, that is, rising when the Sun sets, and setting when the Sun rises.

Mars, and the other superior planets, appear to move from west to east round the Earth; but their motions are sometimes direct, sometimes retrograde, and sometimes they appear for several days to be stationary in one part of the heavens. Mars is stationary when he is about 137 degrees from the Sun; then his motion becomes retrograde, till he comes again within 137 degrees of the Sun, when his motion is direct, and continues so for about 73 days; it now approaches the Sun, and at length is lost in the evening in its rays.

Let A B C, fig. 9, represent the orbit of the Earth,

F G H the orbit of Mars, and L M the sphere of the fixed stars: now when the Earth is at *x*, and Mars at *n*, the planet is said to be in opposition to the sun; but if, while Mars is at *n*, the Earth is at *z*, it is said to be in conjunction. The Earth moves faster than Mars; while the Earth moves from *w* to *x*, Mars will move from *o* to *n*; and while the Earth moves from *x* to *v*, Mars will have travelled from *n* to *m*. It is clear that while the Earth is moving from *w* to *v*, Mars, which has actually moved from *o* to *m*, will appear to have had, among the fixed stars, a retrograde motion from *a* to *c*. Hence, a superior planet, for the same must be true of Jupiter, Saturn, &c., is retrograde while it is travelling in opposition. But if the Earth be at *z*, and the planet at *n*, then, while the Earth moves to *u*, *p*, &c., the planet Mars moves to *m*, *q*, &c., and appears to move in a direct order. As, then, a superior planet appears to move sometimes direct, and sometimes retrograde, it must appear stationary at the two points where the motion changes from one to the other.

When the planet is in opposition at *n*, it will be full-faced; so it will to a spectator at *z*; but if *k* be the position of the planet, then a spectator on the Earth will have a small portion of the dark part turned to him, and it will not be full orbed to the Earth, but appear gibbous, like the moon a little before or after it is full. But if the planet be at a very great distance from the Sun, compared with the Earth's distance, there will be so little of the dark part turned towards the Earth, that it will, as to sense, appear full orbed. This is the case with Jupiter, Saturn, and the Herschel, which between

conjunction and opposition are observed to appear full orbed on account of their great distances.

There is a great analogy between Mars and the Earth; their diurnal motion is nearly the same; they have nearly the same inclinations to the ecliptic, and therefore their seasons are not much different. Dr. Herschel has no doubt, that it has a considerable atmosphere, and that the bright spots, visible in its polar regions, arise from the reflection of the light from the mountains covered with ice and snow. The figure of Mars is that of an oblate spheroid, whose equatorial diameter is to the polar one as 16 to 15 nearly.

In the interval between Mars and Jupiter, four smaller bodies have been discovered revolving in orbits considerably inclined to the ecliptic. Dr. Herschel denominates them asteroids, and they have been named by the astronomers who made the discovery, Ceres, Pallas, Juno, and Vesta: the first was discovered by M. Piazzi, the second and fourth by Dr. Olbers, and the third by M. Harding.

Jupiter is the largest of all the planets, his diameter is eleven times as great as that of the Earth, and, as bodies are to one another as the cubes of their diameters, Jupiter is 1331 times larger than the Earth; but the force of gravitation at his surface is only triple the terrestrial gravitation. The figure of Jupiter is evidently an oblate spheroid, the longest diameter being to the shortest as 13 to 12. His rotation is from west to east, and the plane of his equator is nearly coincident with that of his orbit; so there will be scarcely any difference of seasons in that planet. He revolves round the sun in

about 12 years, at a little more than 5 times the Earth's distance from the sun, of course he enjoys 25 times less light and heat than what the inhabitants of the Earth experience. His rotation is performed in less than ten hours. With a good telescope, certain appearances may be observed on the surface of Jupiter, called belts, which are variable in number and position; sometimes only one is visible, sometimes seven or eight have been seen at once.

Jupiter has four moons constantly accompanying him; all of them, on account of their great distance, seem to keep near their primary, and their apparent motion is a kind of oscillation like that of a pendulum, going alternately from their greatest distance on one side, to the greatest distance on the other. When a satellite is in its superior semicircle, or that half of its orbit which is more distant from the Earth than Jupiter is, its motion appears to us direct, or according to the order of the signs; but in its inferior semicircle, that is, when it is nearer to us than Jupiter, its motion appears retrograde. The satellites of Jupiter must frequently be eclipsed, and from these eclipses the longitude of unknown places is discovered; for the times of the eclipses are calculated for the meridian of the Royal Observatory at Greenwich, and put down in the Nautical Almanack, which is always published some years beforehand, and, therefore, the times of their happening at other places may be compared, and the difference of time turned into degrees and minutes, gives the longitude from Greenwich.

Example. By the table I find that, on the 2d of September, of the present year (1810), there is an eclipse of Jupiter's first satellite at 2 hours, 13 minutes, 28 seconds; but if on board a ship, or at any unknown place, I find it to happen 4 hours, 1 minute, 48 seconds, I know the difference of time is 1 hour, 48 minutes, 20 seconds, which, converted into degrees, will give 27 degrees, 5 minutes east longitude from Greenwich; for each hour of time is equal to 15 degrees; of course, 1 hour, 48 minutes, is equal to 27 degrees; and 20 seconds of time is equal to 5 minutes calculated on the equator.

The diameter of Saturn is ten times as great as that of the Earth; consequently its bulk is a thousand times the bulk of the Earth; but on account of the smaller density of its substance, the force of gravity at his surface is but little more than it is at the surface of the Earth; in other words, the substance that weighs a pound or a ton here, would not weigh much more at Saturn, but on the surface of Jupiter it would weigh three pounds or three tons. Saturn revolves in his orbit in less than 30 years, and his rotation on his axis takes but little more than 10 hours. He is accompanied by seven satellites, two of which were discovered by Dr. Herschel. The most remarkable circumstance attending this planet is the appearance of a double ring about him, suspended over his equator, and revolving with a rapidity almost as great as that of the planet. The light reflected from the ring is generally brighter than that of the planet; for the ring appears sufficiently

bright when the telescope affords scarcely light enough to observe Saturn. The dimensions of the rings and spaces are as follow:

	Miles.
Inner diameter of the smaller ring	146,345
Outside diameter of do	184,393
Inner diameter of the larger ring	190,248
Outside diameter of do.	204,883
Breadth of the inner ring	19,474
Breadth of the outer ring	7,260
Breadth of the vacant space, or dark zone	2,927

The Herschel, so called from its discoverer, revolves in 83¾ of our years, at a distance from the sun equal to 19 times that of the Earth. Its diameter is more than 4 times that of the Earth, yet it can rarely be discovered by the naked eye.

It appears from the foregoing observations, that Mercury, Venus, and Mars, are opaque bodies, because they do not always shine with full faces, that part towards the Earth, which is not towards the sun, being dark. Jupiter and Saturn cast shadows and eclipse their satellites, and, therefore, must be opaque bodies, and hence it is inferred, that the Herschel is also an opaque body, though, hitherto it has not been in a situation to eclipse its satellites.

Comets are solid bodies revolving in very eccentric ellipses about the sun in one of the foci, and are subject to the same laws as the planets, but they differ from them in appearance. They exhibit but a faint light, and generally as they approach the sun a tail begins to appear, which increases till the comet comes to its perihelion, then it decreases and vanishes.

Upwards of 500 comets have been observed at different times, and the elements of the orbits of more than 100 have been correctly ascertained.

By the elements of a comet's orbit are meant, the place of the perihelion, or nearest approach to the sun, the time of its passage through the perihelion and perihelion distance, place of the node and inclination of the orbit to that of the earth.

By comparing the elements of comets together, several have been identified, and their periodic revolutions thereby determined. This was the case with the comet of 1682, the return of which was predicted by Dr. Edmund Halley, from the remarkable coincidence of its elements with those of 1531 and 1607. This prediction was completely verified by the re-appearance of the comet in 1759, seventeen years after the Doctor's death, though in rather an unfavourable position to be seen from our earth. The same comet will appear again in the year 1834, its period being 75½ years.

The most remarkable comet that ever appeared is the one observed in 1680. In its perihelion it approached so near to the sun as to be less than one-sixth of his diameter from him. It is supposed by Sir Isaac Newton to have a period of 575 years, and tobe the same as is recorded to have been seen in the years 1106 and 531 of the Christian æra, and 44 before Christ.

The comet of 1810 and 1811 was a very splendid and beautiful orbit. The French astronomers have calculated its orbit, and suppose it to have a period of 2400 years; but by others it is thought to be the same as that which appeared in 1300 and 1301, which would

make its period only 510 years. The plane of this comet's orbit is nearly perpendicular to that of the earth.

But the comet which has perplexed astronomers more than any other, is that which was seen in 1770. It is supposed to have a period of not more than seven years and a half, though it never has been seen since.

The calculation of the orbit of a comet has always been considered as one of the most difficult problems in astronomy. This arises partly from our not being able to trace them through any considerable part of their orbits, and partly from their being such ill-defined objects as to render it almost impossible to determine with accuracy their apparent places in the heavens.

You still, perhaps, wonder how the magnitude of the earth, and the distances of the sun and planets from it, are ascertained. The subject does not admit of a very easy explanation, but yet, I trust, I can say enough to satisfy your mind, that the thing is possible, though you have not acquired a sufficient knowledge to perform the task yourself. I will begin with the measure of the earth.

Let A B C D, fig. 2, of miscellaneous plate ii. represent the earth, *a* a star in the zenith of an inhabitant at A, and *d* a star one degree to the northward or southward of *a* ; then, if an observer proceed from A towards B, until he get the star *d* in his zenith, or, what is the same thing, until he get *a* one degree to the south or north of his zenith, he will have moved over one degree of latitude on the earth. Let this point be D, and let him measure the distance of A from B, which he will

find to be $69\frac{2}{10}$ of an English mile; but if $1° = 69\frac{2}{10}$ of a mile, 360°, or the whole circumference of the earth, will be equal to 24,912 miles.

The distances of the sun, moon, or planets, from the earth are found by means of what is called their parallax. By parallax is meant the apparent change of situation in any object, arising from a change of place in the observer. Thus, for instance, suppose I were to see a star from my parlour window, just over the top of the building which is opposite to me;—if I go up into the drawing-room, I shall see the same star some distance above it. Now this can only arise from an apparent change of place either of the star or of the building; that it is not in the apparent situation of the star is evident, because we know from experience, that no change of place on our globe, however great, can produce any sensible change in their places, so prodigiously distant are they from us; it must arise, therefore, from an apparent change of place in the building, and this change is called parallax.

Now, in place of a fixed star and a building, let us suppose a fixed star and the moon, the case will be just the same, with this difference only, that the moon being much more distant, it will require a proportionably greater change of place in order to render her parallax sensible to the spectator.

Let N B E A S represent half of our globe, then will Z be the zenith of a spectator under the line at E, and let *a* and *b* be two places, one 30° to the northward, and the other 30° to the southward of E, then will a star at Z appear to a spectator at *a* 30° north of his zenith, and

to a spectator at *b* the same star would appear 30' south of the zenith, and this would also be the case with the moon, were she at the same immense distance; but it is found from observation, that when the moon is in the zenith of a spectator at E, she appears $30\frac{1}{2}°$ from the zeniths of the spectators at *a* and *b*, and consequently, that there is a parallax, or apparent change, in her situation in going from *a* to *b*, but the distance between *a* and *b* being one-sixth part of the earth's circumference, is equal to her semi-diameter, and therefore a change of situation equal to the earth's semi-diameter causes a parallax of 1°.

From *a* and *b* draw two lines, one making an angle of $30\frac{1}{2}°$ with $a\ z'$, and the other a like angle with bz'', these lines will evidently meet at M, the place of the moon, and the distance of M from *e* will be found to be about 60 times *ab*, or in other words the moon is 60 semi-diameters, or 240,000 miles from us.

The distances of the sun and planets are found in the same way, but being much greater than that of the moon, their parallax will of course be much less.

This being a very important problem in astronomy, I will now shew you how the same result may be obtained from one station only.

Let B A G be half the earth, S the sun, and *m* the moon, the arc, E K L, is that which represents one fourth part of the moon's path. C R S is the rational horizon to an observer at A, but his sensible horizon is A C; A L C is the angle under which the earth's semi-diameter A C, is seen from the moon L, which is equal, by a theorem in geometry, to the angle L A O; A S C is

the angle under which the earth's semi-diameter is seen at the sun, and is equal to O A *f*. Now, it is found by observation, that the angle O A L, or its equal A L C, is much greater than the angle O A *f*, or its equal A S C, which proves that the earth's diameter A C, as seen from the moon, appears much larger than it does when seen from the sun S, consequently the earth is much farther from the sun than from the moon.

The quantity of the angle O A L is found by observation in the following manner: By means of the quadrant, A D *d*, we find the exact time that the moon takes in passing from the meridian E to the sensible horizon O, which will appear as a quarter of a circle, but it will be less than a quarter of a circle by the arc O L, and O L is the measure of the angle O A L, equal to the angle A L C, which subtends the semi-diameter of the earth.

Now it is known that the moon revolves completely about the earth in 24 hours 48 minutes; of course it takes 6 hours, 12 minutes in passing from E to L; therefore the time taken to pass from E to O, subtracted from 6 hours 12 minutes, gives the time taken to pass through the arc O L, which, turned into degrees and minutes, gives the arc O L, or the measure of the angle O A L, or A L C, the moon's horizontal parallax; then, to find A L, the distance of the moon from the earth, we say, by a rule in trigonometry, as the size of the angle A L C is to A C (or the semi-diameter of the earth, which is known by other means) so is the sine of the right angle A C L, or 90 degrees, to its opposite side A L; this comes out to be about 240,000 miles from the earth.

There are other methods in use which are more ac-

curate, but this will suffice to show you that the thing may be done. To find the length of A S, or the distance of the earth from the sun, is much more difficult, because it is almost impossible, by any common method, to find the quantity of the angle A S C. This, however, is discoverable by the transits of Venus, of which there was one in 1761, and another in 1769, and by these it was determined that the horizontal parallax, or the angle A S C, is equal to $8\frac{2}{3}$ seconds, which gives the distance A C, about 95,000,000 miles.

The distance of the earth from the sun being found, the distances of all the other planets are easily found; because the times of their periodical revolutions are known by observation; but the times are to one another as the cubes of their distances from the sun: thus, if T be the periodical time of the earth in its orbit, and that of any other planet we say as

$T^2 : t^2 :: \overline{95,000,000}|^3 : D^3 =$ the cube of the distance of that planet. Here the three first terms being known, the other is found by the rule of three, and the cube root being extracted, we get the distance of the planet from the sun.

The distances of the heavenly bodies being determined, their magnitudes may be calculated from their apparent diameters; and thus it is that astronomers are enabled to describe the real orbits and the actual magnitudes of the sun, moon, and planets from their parallaxes, and apparent motions and diameters.

Having made you acquainted with the theory of astronomy, I will now endeavour to explain to you some of its practical details, and show you how it enables the

mariner to steer his vessel through the trackless ocean, with a degree of precision that is truly astonishing. You are sufficiently acquainted with geography to know that the situations of places are marked on the earth by means of their latitudes and longitudes. The elevation of the visible pole above the horizon is always equal to the latitude of the place, and the elevation of the equator to the complement of latitude.

The first thing a seaman has to do, is to ascertain his latitude; this is found by taking the altitude of the sun at noon, or of a star at night, whilst passing the meridian. The sun or star's declination being known, the latitude may be found from it by calculation.

The next thing is to find the time at the place of observation, and this is done by taking an altitude of the sun or of a star, two or three hours before or after passing the meridian.

For if the latitude of the place be found from observation, and the declination of the sun or star from the Nautical Almanac, it is easy to compute what should be their altitude at a certain hour, and *v v*, from their altitude to compute the time.

The time thus formed is compared with that shewn by a chronometer carefully set and regulated, so as to shew the time at Greenwich, and from the difference of these times the longitude is deduced.

But however accurate this method may be, it is evidently too precarious to be depended upon, as any accident to the chronometer, or forgetfulness in winding it up, would leave the mariner at a loss how to discover his longitude.



The lunar method, as it is called, is therefore very justly preferred as equally accurate, and only requiring a watch which can be depended upon to shew time correctly for the space of a few hours.

The accurate calculation of the longitude by this method is rather intricate, but the principle upon which it depends is very simple, and easily understood.

The apparent motion of the moon among the fixed stars in 24 hours is upon an average equal to about 12°. In the Nautical Almanac is set down her distance from some of the most remarkable fixed stars, for every three hours of each day at Greenwich; this being the case, it is evident, that by measuring her distance from one of those stars, a seaman can at any time know what o'clock it is at Greenwich, and this, compared with his own time found as before explained, gives him the difference of longitude. The intricacy of the calculation arises solely from the moon's parallax and refraction, which are different in different places.

The instrument used at sea for taking altitudes, or the moon's distance from the sun, or from a star, is called a Hadley's Sextant, from its inventor. The great excellence of this instrument, and what particularly recommends it to mariners, is, that it does not require the same degree of steadiness of support as other instruments: it is also extremely portable, very accurate, and easily adjusted.

ELECTRICITY.

LETTER XXX.

Of the Electric Fluid—Electrical Machine described.

THE earth and all bodies with which we are acquainted, are supposed to contain a certain quantity of an exceedingly elastic fluid, which is called the electric fluid, and which passes through them with more or less facility, according to their different powers of conducting it. This certain quantity belonging to all bodies may be called their natural quantity, and so long as it is undisturbed in a body, it produces no effect; but when any body, or part of a body, becomes possessed of more or less than its natural share, it is said to be electrified, and is capable of exhibiting those appearances which are ascribed to the power of electricity. The equilibrium would never be disturbed, or if disturbed, would be immediately restored, but that some bodies, as glass, wax, &c. do not admit the passage of the electric fluid through their pores, or along their surfaces, though others do.

The effects of the electric fluid are distinguished from those of all other substances by an attractive and repulsive quality, which it communicates to different bodies, and which differ, in general, from other attractions and

repulsions, by their immediate cessation, when the bodies acting on each other come into contact, or when they are touched by other bodies.

It is by excitation that the electric fluid becomes perceptible to the senses, which will be fully explained by the following experiments.

EXPERIMENT I. Let a long glass tube be rubbed with the hand, or with flannel, and it will immediately attract light substances, and give a lucid spark to the finger, or to any metallic or other conducting substance brought near it.

The glass tube is called an electric; and all bodies capable of being excited, so as to produce electrical effects, are called *electrics*.

As the exciting glass tubes was a laborious operation, and the quantity of electricity so obtained was very small, globes and cylinders were invented and made to turn on their axes, and a rubber of leather so applied as to excite the parts of it in contact with the leather. Fig. 1. represents an electrical machine: A is a cylinder of glass so fitted up in a frame as to revolve by means of the handle H; the rubber R, behind the machine, is supported by a glass stem T; the chain O A is intended conduct the electric fluid from the table, and from the earth, by the table, to the rubber; C D is a metallic conductor intended to collect the electric fluid from the cylinder A. The stand M M, which supports the conductor C D is made of glass to prevent the electric fluid from running out of the conductor on the table.

EX. II. Turn the handle of the machine, and if it be well excited, you may, by bringing a knob of brass, or

your knuckle, &c. near the conductor at *z*, get a spark at several inches distance. This distance will vary according to the excitation of the machine. The electricity which is accumulated on the prime conductor C Z, is prevented from flowing away by being placed on the glass leg *m* M, which is a non-conductor of electricity. If it were placed on a moist wooden stand, instead of one of glass, there would not be the smallest accumulation; for, as fast as it was thrown off from the cylinder on to the conductor, it would flow through the wooden stand into the table, and from thence to the earth.

Ex. III. If a person standing on the ground, place his hand on the conductor, and the machine be worked in its highest state of excitation, still there will be no electrical appearances, because, however great the accumulation of electricity on the conductor, it will flow through the hand and body to the earth in perfect silence.

Ex. IV. But if the person stand on a stool supported with glass legs, or by a cake or cakes of rosin, sealing-wax, sulphur, &c. his body, being now insulated, the electricity cannot pass to the earth; and sparks may be taken from any part of him, as it was before from the prime conductor.

By these experiments you perceive the difference between conductors, and electrics or non-conductors: all bodies that transmit electricity are called conductors, such is the human body, such are all metallic substances, and almost all fluids, excepting oil. Those substances that will not transmit the electric fluid are called electrics, or non-conductors. But all substances become

conductors either by heat or moisture. The principal method of exciting the electric fluid is friction, and electricity is most powerfully excited, when an electric and conductor are rubbed against each other; in this case the electric fluid passes from the conductor: thus, if I rub with my hand a glass tube, or a stick of sealing-wax, the electric fluid passes from the hand to the glass or wax. Again, if you examine fig. 1, the electrical machine, the rubber is a conducting substance, and made more powerfully so, by spreading over it an amalgam of mercury and tin, the friction of this against the cylinder collects the fluid from the surrounding substances by means of the chain o *a*. That it proceeds from the surrounding bodies is evident from this circumstance, that if the rubber R be supported by a glass stem o, and the chain taken off, the electrical appearances will be trifling, only those which can be given by the rubber; but if a person place his hand on the rubber while he stands on the ground, then an abundant quantity will be supplied. The rubber is supplied by the quantity taken from the hand and body of the person in contact with it, and these are supplied by the general mass of the fluid that is lodged in the earth.

You are now aware of the meaning of the term *insulated*, which perpetually occurs in this science; when a conductor is surrounded or supported by non-conductors, it is said to be insulated. Thus the rubber R, when supported by the glass stem o *r*, is insulated, because there is no communication between it and the earth. The chain however, gives the communication, and electricity is produced.

Electricity is said to be *positive* or *negative* according to the different effects produced. I suspend two pith balls on silken and parallel threads, and bringing them near an excited glass tube, they will diverge, and remain at a distance from each other till the surrounding air carries off the superabundant electricity. If I bring near them another excited glass tube, they will diverge still farther; but if, instead of a glass tube, I make use of an excited stick of sealing-wax, or rosin, then the diverging balls will, by the influence of the wax or rosin, be instantly brought together. The glass by excitation is supposed to have more than its natural quantity, and is said to be positively electrified; but the wax, by the same process, is supposed to lose a part of its natural quantity, and to be minus, or negatively electrified. These electricities by some are thought to be different in *quality*, rather than in *quantity*, and by them they are called *vitreous* and *resinous* from the substances used. The former is usually denominated the theory of Dr. Franklin; the latter theory was first espoused by Du Fay, and other French philosophers.

The Franklinian system is usually regarded as the most simple, and therefore I shall adopt it; and you will observe, that the two states of positive and negative electricity always accompany each other: for if any substance acquire the one, the body with which it is rubbed acquires the other. When one side, or one end of a conducting substance receives the electric fluid, the whole substance is instantly pervaded with it: thus, sparks may be taken in any part of the electrified conductor A z, fig. 1; but when an electric is presented to an electrified

body, it becomes electrified in a small spot only. The positive and negative electricities cannot come together, but by means of a communication with conductors; but the instant there is a communication between the two electricities, their electrical effects are destroyed, and the act of their union produces an electric spark, and if the union be made by different parts of the body, a sensation will be felt more or less painful, according to its strength: this is called the electrical shock.

Ex. v. In fig. 2, you have a representation of an electrical jar, called a Leyden phial: it is a glass jar, open at one end; the cover at top is wood, pierced to admit a brass wire and chain lying at the bottom; the top of the wire is terminated with a brass knob. The jar is lined inside and outside with tin-foil, to within two or three inches of the top, because the electric fluid will accumulate on the tin-foil, and easily flow from the inside to the outside, when a conducting substance is brought to touch the outside foil, at *a*, and the knob x, which communicates with the inside by means of a chain that rests upon the bottom of the jar.

The jar is electrified by bringing the knob *x* to the prime conductor, when the machine, fig. 1, is worked; and it may be discharged by any conducting substance; for if one hand touch the outside of the jar, and the other be brought to the knob *x*, the electric fluid will pass instantaneously through the arms from the positive to the negative side.

A number of these jars united, as in fig. 3, is called an electrical battery: the insides are connected by means of the wires and chains, and the outsides are connected

by being all placed in a box, the bottom of which is covered with tin-foil. Supposing the battery charged by means of the electrical machine, and with the rod A B C, it may be instantly discharged.

Sometimes the battery is sufficiently large, and so powerfully excited as to melt the wire *x* in its passage. By this means, small animals, as birds and mice, have been killed in a moment: gunpowder, spirits, and other bodies may be inflamed.

I will now describe a few experiments which may be easily made with an electrical machine; observing first, that bodies which are charged with the same electricity repel each other; but if one have more, and the other less than its natural share, they will attract one another.

EX. VI. If a tuft of feathers be placed in the hole *z* of the prime conductor, and the machine be then worked, the feathers will endeavour to avoid one another, and stand erect at a distance; because all of them being electrified by the same electricity, they repel each other. Take the electricity from the conductor, and the feathers will instantly collapse.

EX. VII. Suspend a metallic plate from the conductor, and underneath it, at the distance of three or four inches, put another plate of the same size, or larger; on this place some small pieces of paper, or some bran or sand, and work the machine; the paper, &c. will jump to the upper plate, from which they will be repelled, and fly and discharge themselves upon the lower plate, after which they will be attracted and repelled again, and so continue till the electricity of the upper plate is discharged.

Ex. VIII. Take a little bit of cotton, or a light downy feather, lay it upon the palm of your hand, and hold it four or five inches from the prime conductor; turn the machine, and the cotton or feather will fly to the prime conductor, and from the prime conductor to the hand, with a very quick motion, and continue as long as the machine is turned. In this experiment, the prime conductor being strongly electrified, attracts the unelectrified cotton or feather, and electrifies it, then repels it to the nearest conductor, viz. the hand: there the cotton deposits its electricity, and is again attracted by the prime conductor.

Ex. IX. Fig. 4 represents a set of bells, the middle one of which is to be connected with the prime conductor: the moment the machine is set to work, the bells will begin to ring, because all the bells and clappers, except the middle one, are hung on silk, and all excepting the middle one are connected with the earth by means of the chains. The centre bell, having more than its natural quantity of electricity, attracts the clappers, and they are repelled to the outside bells, where they deposit the electricity which they carry from the centre one z.

Ex. X. Let a person standing on an insulated stool, hold in his hand a spoon filled with highly rectified spirit of wine, and made warm by heating the silver spoon, if another person take sparks from the spirit, it will be instantly inflamed.

Ex. XI. Introduce the blunt end of a wire into the hole of a prime conductor, and let the other end be drawn to a point, on which place another horizontal

wire, four or five inches long, but its ends bent in acute angles. Work the machine, and electricity will issue out of each point, resembling a star; and if it be made to turn upon its centre, and the machine act very powerfully, the flame will appear as one continued circle of fire.

Ex. XII. If a person stand on the insulated stool, holding a shilling or half-crown between his teeth, and another person not insulated take a spark from it, the sensation will be so severe as to make him drop the money, unless his lips touch it.

Ex. XIII. The Florence flask used in electrical experiments, is nearly exhausted of air, having a brass cup and ball fixed to its neck: if it be held by the brass work, and be rubbed pretty briskly, it will be slightly luminous within; but if the ball be presented to the prime conductor while the machine is at work, the appearance will be extremely beautiful, and will remain so some time after it is removed from the prime conductor.

Ex. XIV. A word of any kind is illuminated in the following manner, on a long slip of glass: the word is made with tin-foil in parallel lines, separated at different places, to cause sparks to pass from one piece to another, the word is exhibited by the passage of the electricity over the tin-foil.

Electricity and lightning are undoubtedly effects of the same cause. Every effect of lightning may be produced by electricity, and every experiment in electricity may be made with lightning, by conducting it from the clouds to a convenient place, by means of insulated rods,

or by kites raised in the air, a method which was discovered by Dr. Franklin; and it is found, that in the natural, as in the artificial electricity, there is the positive, and also the negative. The ascending electricity in the air is said to be negative, because it leaves bodies in a negative state. The descending electricity, or that which passes from the higher parts of the atmosphere to the earth, is called positive electricity, because it renders all bodies electrified by it, in a positive state.

The knowledge of this branch of science has been applied to various practical purposes; as the defence of buildings from the dangers of lightning, and to the art of healing.

High buildings are protected from the dire effects of lightning, by fixing to them one or more pointed metallic conductors, which are elevated a few feet above the building, and are continued to the earth, and a few feet below its surface; these convey the lightning of electrified clouds silently away, which might otherwise strike the building, and do much mischief.

Electricity is used for medical purposes, by giving the patient sparks, or slight shocks: this is best effected by machines contrived by Mr. Nairne for the purpose. But sparks may easily be given to, or taken from, the body, by the most common electrical machines. Electricity has been successfully used in the cure of deafness, rheumatisms of long standing, the ear-ache, tooth-ache, &c.

GALVANISM, OR VOLTAISM.

LETTER XXXI.

Origin of Galvanism—Experiments—Galvanic Circles—Voltaic Batteries—Decomposition of Water—Voltaism and Electricity compared.

It is now, my dear sir, more than half a century since the first electrical shock was felt by M. Muschenbroek, which, at that period, excited the attention of all the philosophers in Europe. The theory of the Leyden phial was soon explained; and thence the powerful effects of batteries were called in aid of the experimentalist. After this, it was discovered that certain fishes had the power of producing shocks on the human frame similar to those given by the electrical jar. Of these fishes there are three very remarkable; viz. "the Torpedo, the Gymnotus Electricus, and the Silurus Electricus." From this circumstance, and from the convulsive motions excited in dead animals, by means of electricity, we had a branch of science devoted exclusively to animal electricity; but about the year 1791, it was observed by Galvani, that electrical effects could be produced on animals without the aid of an electrical apparatus, and, apparently, by different means. This discovery, which has led to the most important and

brilliant series of facts, was the effect of accident. Galvani, professor of anatomy at Bologna, having noticed certain involuntary motions or contractions in the muscles of some dead frogs, which had been suspended on the iron palisades of his garden, found, upon a more minute examination, that he could produce these contractions at pleasure, by touching the lifeless animal with two different metals, provided the metals were at the same time in contact with each other.

If in an animal (as a frog), recently dead, the muscles and nerves being prepared for the purpose, a communication be made between a muscle and nerve by some conducting substance, or substances connected together, as silver and zinc, the limb will be put into motion.

EXPERIMENT I. If part of the nerve of a prepared limb be wrapped up in tin-foil, or be laid only upon zinc, and a piece of silver be laid with one end upon the muscle, and the other upon the tin or zinc, the motion of the limb will be violent.

EX. II. Place two wine-glasses full of water near each other, and put the thighs and legs of a frog, as fig. 5, into the water of one glass, and lay the nerve C D, covered with tin-foil, over the edges of the two glasses, and just touching the water; let now a communication be made between the water in the glasses by means of silver, or by putting the fingers of one hand into the water of the glass that contains the legs, and holding a piece of silver in the other; if then, you touch the coating of the nerves with it, the legs will be so violently excited as sometimes actually to jump out of the glass.

These convulsive motions may be excited not only in dead, but in living animals, particularly in frogs, eels, flounders, &c.

Ex. III. Place a living flounder upon a plate of zinc, pasting upon its back a slip of tin-foil, then form a communication between the zinc and the tin-foil by means of a wire, &c., and the same kind of contractions will take place as are witnessed in dead animals.

The taste and the sight may be affected by galvanism.

Ex. IV. If you lay a piece of zinc upon your tongue, and a piece of silver, as a half-crown, under it, and then form a connection between them by bringing the edges together, you will find a peculiar taste or sensation which is not produced by the metals separately, or indeed together, provided they are not brought into contact.

Ex. V. To affect the sight, you may put a piece of zinc between the upper lip and gum, as high as possible, and a piece of silver upon the tongue, and whenever the two metals are made to communicate, by touching one another, a flash of light will be distinctly seen.

The conductors of this fluid, if it be a fluid, differ from each other in their conducting power; they are divided into perfect and imperfect conductors. The perfect conductors consist of the metallic substances and charcoal, these are termed conductors of the first class. The conductors of the second class, or imperfect conductors, are water, and the mineral acids, and all substances that contain these fluids.

The most simple combinations capable of exciting the galvanic effects must consist of three different bodies, viz. of one conductor of one class, and two diffe-

rent conductors of the other class; thus, in the experiments just referred to, there are the silver, the zinc, and the saliva. Here are two perfect and one imperfect conductor, and it is called a galvanic circle of the first order. Where only one perfect and two imperfect conductors are used, it is called a circle of the second order.

It was soon ascertained, that if a single combination of three conducting substances produced a certain effect, a second and a third would produce a double and treble effect, and so on. The combinations are now denominated Voltaic piles or batteries, from Volta, an ingenious Italian, who improved the science, or rather, who, seizing the first ideas of Galvani, improved upon them so much, as to render it a new science in his own hands.

The earliest effort in this way was a pile, consisting of alternate layers of zinc, copper, and moistened woollen cloth. One of these piles is represented by fig. 6; the layers consist of round pieces of metal, and cloth, and they are placed in exact order, zinc, copper, cloth; this is necessary, because it is found that there is a positive and negative end; and, of course, in every complete circle, the electric fluid circulates in one way only. If, therefore, two equal simple combinations were so arranged, that the two currents opposed each other, they would be annihilated, and produce no effect; *z* and *x* are two pieces of wood, made to slide on the rods *a b c*, which are of glass, and so placed as to prevent the pile from falling.

Ex. vi. If, now, the pile be in action, and a person

put one hand to the lower stratum of zinc, and the other to the upper stratum of copper, he will feel an electric shock, in a greater or lesser degree, according to the height of the pile.

In fig. 7, we observe a different kind of battery, consisting of a row of finger-glasses, or china cups, containing a weak solution of nitrous acid in water; into each is plunged a plate of zinc, *z*, and a plate of silver, *s*, fastened together by curved wires, *w*.

Ex. 7. If, instead of three or four glasses, there were twelve or twenty, arranged in the same manner, and you were to put one hand in the first and the other in the last, you would perceive a considerable shock.

We have, in fig. 8, a more convenient battery: it consists of a trough made of wedgewood ware, divided, as is exhibited in the figure, and at each division there is a plate of zinc, and one of copper; between the divisions is a solution of acid and water, the two wires *w w* connect the positive and negative ends of the battery, and if the battery be sufficiently large, the most interesting and brilliant experiments may be produced. Glass, you know is a non-conductor, therefore the small tubes *x* and *z* slide on the wires, that the operator may handle them without danger of a shock. The square plate G is likewise glass.

Ex. VIII. If charcoal, gunpowder, gold or silver leaf, &c. be placed on the glass G, and the two wires be brought together, as in the figure, the substance, thus exposed to their action, will be instantly deflagrated.

It should, however, be observed, that, to produce an action equal to this effect, there must be several such

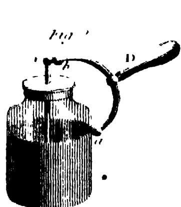
batteries as that represented in fig. 8, united by metallic cramps, such as fig. 9. The battery used at the Royal Institution consists of so many plates as to make a surface of metal equal to many thousand square feet.

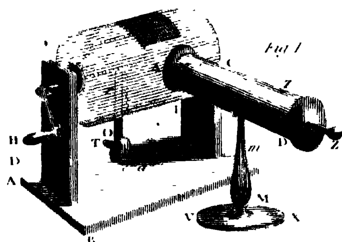
You are already apprised, that water is not a simple substance. It was by the modern improvements in chemistry that the discovery was made, that this fluid, one of the elements of the ancients, is a compound of two gases or airs, denominated oxygen and hydrogen. By electricity, and by voltaism, water has been decomposed, or reduced to these gases: and by the same agents water has actually been produced by the union of these gases in a certain proportion, viz. of about 80 parts of hydrogen to 20 of oxygen.

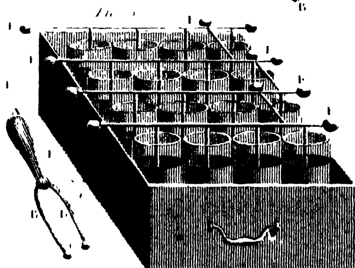
Ex. IX. Fill a small glass tube, A B, fig. 10, with very pure distilled water, and connect the wires, which pass through the corks, with the zinc and copper wires, *z c*, of the battery, fig. 9, and almost immediately a stream of gas proceeds from that wire which is connected with the negative end of the battery, which is hydrogen gas; from the other wire oxygen gas is evolved. The hydrogen may be collected, but the oxygen unites with the wire, unless both the wires proceeding from the battery be of gold or platina, which are not oxydable, then the two gases may be collected together, and if presented to a candle, will explode with great violence, which proves, that they consist of hydrogen and oxygen.

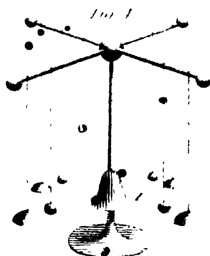
Without entering farther into the subject, you will, from the foregoing observations, be able to draw for yourself some conclusions, viz. that voltaism appears to

be a peculiar mode of exciting electricity, by the chemical action of certain bodies upon one another. The oxydation of metals produces it in great quantities. It is by the oxydation of the metallic plates, made use of in the batteries already described, that the voltaic effects are produced, of course the action is greatest when the troughs, &c. are first filled with the fluid, and it becomes less and less till the plates are completely oxydated, when it ceases; the plates must then be removed, and the oxyde cleaned off before they will be fit for farther experiments. The nerves of animals are more easily affected by voltaic electricity than other substances; and to prove the similarity between this and the common electricity, it may be noticed, that the same substances are conductors and non-conductors of both. By both, Leyden jars may be charged, and shocks given to one, or many persons holding hands; but when voltaic electricity is used, the hands must be moistened with a solution of salt and water. The electric shock produced by the torpedo, Silurus Electricus, &c. is very analogous to that produced by the voltaic battery.



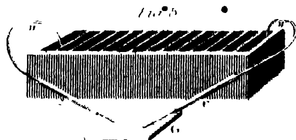






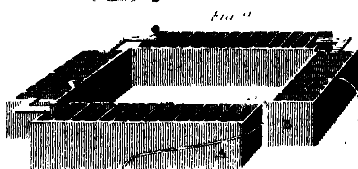














MAGNETISM.

LETTER XXXII.

Magnet described—Its Properties—Magnetism communicated to Iron and Steel—Experiments—Magnetic Meridian—Polarity of the Magnet useful to Mariners—Artificial Magnets—Variation of the Compass—Dipping of the Needle—Horse-shoe Magnets—Mariner's Compass.

MAGNETISM is another branch of science with which it is necessary you should be acquainted. It derives its name from the loadstone, or natural magnet, a very singular substance, not much unlike the ore of iron, which was well known to the ancients for its property of attracting iron. But it was not till the beginning of the 14th century, that this most important property was applied to the conducting vessels over seas to foreign countries. Till this period, mariners had scarcely ever ventured to quit sight of land, not knowing, if they did, by what possible course they could return. To exhibit the attractive power of the magnet is shewn the following

EXPERIMENT. If a magnet and a piece of iron be placed on pieces of cork on a vessel of water, and brought to within a certain distance, they will attract one another,

and if equal in weight, they will meet in a point half way between the two.

This attractive property of the natural magnet may be communicated to iron and steel, by which means they also become magnets, and will produce the same effects on other iron and steel. Iron or steel thus converted are denominated artificial magnets. Soft iron acquires magnetism with more ease than hard iron or steel, but the latter will retain it much longer; and what seems very surprising is, that the magnetic virtue is not diminished, but rather increased, by communication. It is most active at the two opposite points, which are denominated the poles, from their correspondence with the poles of the earth.

Ex. II. It is found, by placing the magnet on a piece of cork floating on water, so that it may turn freely, it will arrange itself in the direction of the poles of the earth, namely, north and south, but not accurately so.

Ex. III. To find the poles of a magnet, place it under a smooth piece of paper, and sift some steel filings on the paper, which will arrange themselves in curves. At each end of the magnet the filings will take a straight direction, and those which are situated at a small distance from the poles, will assume more or less of the curve, in proportion to their distance from them.

The readiest and most convenient way of discovering whether a piece of metal is magnetic, is by means of a small compass needle; for if it contain iron which is not magnetised, every part will attract either end of the

compass indifferently; but if it be magnetised, then its north pole will attract the south, and repel the north pole of the needle; and, *vice versâ*, its south pole will attract the north, and repel the south pole of the needle.

There are various methods of giving the magnetic property to iron or steel, but in these there is need of a real magnet; in some cases, indeed, the property is acquired without the use of another magnet.

EXAMPLES. A piece of iron brought sufficiently near a magnet becomes itself a magnet. Bars of iron that have stood a long time in a perpendicular direction, are frequently found to be magnetical. If a long bar of hard iron be made red hot, and then suffered to cool in the direction of the magnetical line, it becomes magnetical. Lightning, and the electric shock, will sometimes give polarity to iron and steel.

Artificial magnets are made by applying one or more powerful magnets to pieces of steel; and a needle, adapted to a compass, is made by fastening the steel on a piece of board, and drawing magnets over it, with a heavy hand, from the centre outwards.

The power of a magnet is not diminished by communicating its properties to other bodies; and it is much increased by the addition of iron gradually. Two or more magnets joined together may communicate a greater power to a piece of steel than either of them possesses singly.

A magnet bent so that the two ends almost meet, is called a horse-shoe magnet. Magnets are made so to increase the action, because it is found, that both poles

together attract with much greater energy than a single one, and in this shape they are easily made to act at the same time on the same body.

If two soft pieces of iron are applied to the poles of a bar-magnet, and made to project in the same direction, they not only become magnetical themselves, but may, in this situation, be made to act at the same time, on the same piece of iron. The magnet, in this case, is said to be "armed," and the pieces of iron are called the armature; to avoid the necessity of this, horse-shoe magnets are used. Magnets should not be left with two north or south poles together, for, in this position, they destroy each other's polarity, or, at least, very much diminish it. Bar-magnets should always be left with the opposite poles laid against each other, or by connecting their opposite poles by a bar of iron; hence, a small bar of iron is always placed at the ends of a horse-shoe magnet, which not only preserves the power of the magnet, but prevents it from acting on surrounding bodies.

If a needle before being magnetised be suspended on a horizontal axis passing through its centre of gravity, it will rest in any position in which it may be placed; but no sooner is it magnetised, and brought into the magnetic meridian, than it takes an inclined position, making in this country an angle of 71° or 72° with the horizon, the south pole being elevated, and the north pole depressed.

Soft iron instantly imbibes the magnetic fluid, and as instantly loses it; hardened iron is difficult to magnetise, but then it retains the magnetic virtue permanently.

Ex. iv. Take a bar of soft iron, a kitchen poker which has been long in constant use will answer the purpose,—place it parallel to the magnetic axis of the earth, and it will instantly become magnetic, as may be seen by bringing a small compass needle close to it; reverse it, it will still be magnetic, its poles changing with its change of position.

The magnetic poles are not directed towards the same part of the heavens as the poles of the earth. Indeed, the magnetic axis does not seem to pass through the centre of our globe, for the north and south magnetic poles are not antipodes to each other.

The north magnetic pole is supposed to be situated somewhere about latitude 70° north, and longitude 100° west of London; whilst the south magnetic pole seems to be somewhere about latitude 65° south, and longitude 130° west of London.

Since the magnetic poles do not coincide with the poles of the earth, it is evident, that the needle cannot point due north and south, except in those countries where the magnetic and true meridian coincide.

This deviation of the magnetic from the true meridian is called the variation of the needle. In London it is at this time about 24° to the westward. The inclination of the needle to the horizon is called the dip. The dip is found to increase as we approach the magnetic poles, where, according to theory, the needle ought to take a perpendicular position.

When the needle was first known in this country, the variation was to the eastward; about 1657 it pointed due north in London. In 1817, it was about 24° 17′

west; and, since then, it has been slowly returning towards the true meridian. Hence it appears, that the magnetic poles are not permanent, but probably revolve round some central point in a period of about 600 years.

The needle is subject to a small diurnal variation. About eight o'clock in the morning it begins to move westward till two in the afternoon, when it gradually returns. The diurnal variation is probably occasioned by the heat of the sun.

The Aurora Borealis is found to derange the needle very considerably, particularly in high latitudes: in Sweden it has been observed to amount to as much as 6° or 7°.

The Aurora Borealis always appears in the direction of the magnetic pole. In the late voyage to the Arctic Sea, this phenomenon appeared in the south, the ships being then to the northward of the north magnetic pole.

The cause of magnetism is little understood; the discoveries of Professor Oersted, however, have thrown considerable light on the subject, and plainly indicate, if not the identity, at least a close connection, between magnetism, electricity, and galvanism.

If the extremes of a voltaic battery be connected by a platinum wire, the wire becomes heated; and, if very small, suffers ignition. Suppose such a wire to be laid upon the positive and negative conductors of a voltaic apparatus; bring the north pole of a common magnetic needle below and at right angles to the platinum wire, and it will be repelled; remove the needle, so that it

may still be at right angles to the wire, but with its north pole above it, and it will be attracted: if the electric poles be reversed, those phenomena will also be reversed.

If the conjunctive platinum wire be placed vertically instead of horizontally, it will occasion the needle to oscillate, but in no part will it permanently attract or repel the needle.

If a small steel bar be attached to the conjunctive wire, and parallel to it, it is not polarised; but if it be attached to it transversely, it becomes permanently polarised.

To render a steel bar magnetic, it is not necessary that it should actually touch the conjunctive wire, for the electro-magnetic influence is conveyed to a considerable distance, and is not excluded by the interposition of a plate of glass, of metal, or of water.

If two conjunctive wires be placed parallel to each other, and so attached to the voltaic battery as to have their opposite ends attached to the same pole, they will attract each other; but if so placed as to have the contrary ends attached to the same pole, they will repel each other.

These experiments of Mr. Oersted have been repeated and verified by Mr. Ampere, Sir Humphry Davy, Dr. Wollaston, and others.

I will now conclude what I have to say on this subject with a description of the "mariner's compass."

This instrument, always to be met with on board of ship, consists of three parts, the box, the card, or fly, and the needle. The box which contains the card and

needle, is made of wood, brass, or copper, and is of a circular shape. It is suspended within a square wooden box by means of two concentric circles called gimbals, so fixed by cross axes, in the manner of the rolling lamp, see MECHANICS, that the inner one, or compass-box, retains a horizontal position in all the motions of the ship, while the outer or square box is fixed, with respect to the ship. The compass-box is covered with a pane of glass to prevent the card from being disturbed by the wind. The card is a circular paper fastened upon and moving with the needle. The outer edge of the card is divided into 360 parts or degrees, and within the circle of those divisions it is again divided into 32 equal parts, which are called the points of the compass or rhumbs, each of which is again subdivided, and the letters N., NE., ENE., &c., are marked. The magnetic needle is a slender bar of hardened steel, with a hole in the centre, to which a conical piece of agate is adapted; this turns on a pin fixed in the middle of the box, and is obedient to every change in the direction of the ship to which the compass is attached.

.MISCELLANEOUS.

LETTER XXXIII.

Length of a Pendulum vibrating Seconds, as determined by Captain Kater—The construction of achromatic Telescopes explained—Heating and Chemical Rays—Magnetism by violet Rays—Double Refraction—Polarisation of Light.

MY DEAR SIR,

YOUR answer to my last letter gives me the greatest satisfaction, as it evinces a close attention to the subjects recommended to your notice, and a laudable desire of obtaining a more complete knowledge respecting them.

You ask me to explain to you Captain Kater's method of determining the length of a pendulum vibrating seconds. The construction of achromatic telescopes, and what is meant by the polarisation of light.

The difficulty of obtaining the actual length of a pendulum arises from this circumstance, that the centre of oscillation, though a real, is an invisible and untangible point, and consequently that its distance from the point of suspension cannot be measured with any thing like precision.

It is now upwards of a century and a half since Huyghens first applied the pendulum to clocks; and it

is to that great mathematician we owe the demonstration of this curious and important theorem, namely, that the centres of suspension and oscillation of a pendulum are mutually convertible into each other; that is to say, if a pendulum vibrating in any given time whilst hanging in one position, be inverted and suspended from what was then its centre of oscillation, its former point of suspension will now become the point of oscillation.

Fig. 7. of miscell. plate i. represents a pendulum similar to that employed by Captain Kater. It consists of a rod *a b*, with a large bob *b*, fixed at one end, and a smaller bob *c*, moveable along the rod at pleasure. This pendulum is capable of being suspended either at *a* or *b*.

First let the pendulum be suspended by the point *a*, and the time of its vibration noted; then from the point *b*, and if its vibrations be the same in this as in the former position, it needs no adjustment.

But if the vibrations in the two positions be unequal, move the bob *c* towards *a* or *b*, as occasion may require, until the vibrations are perfectly isochronal.

The pendulum being thus adjusted, it is evident from the theorem of Huyghens, that *a* and *b* will become mutually points of suspension and oscillation to each other. All that remains, therefore, is carefully to measure the distance of these points from each other, which distance will be the length of the pendulum.

In this manner Captain Kater determined the length of a pendulum vibrating seconds in the latitude of London, to be 39,138 inches English measure.

I will now explain to you in what respect achromatic

telescopes differ from those of the ordinary construction.

White or common light, as you know, is a heterogeneous substance consisting of various rays of different colours and different degrees of refrangibility. In consequence of this latter property every ray has its particular focus, so that a convex lens, instead of producing one colourless image, produces a number of different coloured images, lying, as it were, upon each other, which makes objects appear ill defined, and surrounded with coloured fringes.

Let A B fig. 4. miscell. plate ii. represent the convex object-glass of a common telescope, S A, S B, rays of light from the sun, moon, or any other luminous body falling upon it. The light composing these rays is decomposed in passing through the glass by their unequal refraction, the red rays converging to a focus at R, the violet at V, and the other colours to intermediate points between V and R.

There are two sorts of glass used in the construction of telescopes, crown glass and flint glass; the former is the most transparent, and therefore generally preferred for single object-glasses, the latter possesses a greater refractive power over all the rays, particularly over the violet.

By combining these two sorts of glass, the optician is enabled to correct the error of each, and to form an achromatic object-glass, that is, a glass which shall bring all the rays to the same focus.

Suppose A B, fig. 5, to be a convex lens of crown glass, the rays S A, S B, as in the former case, would be

decomposed, the violet coming to a focus at V, and the red at R. To prevent this, the concave lens C D, of flint glass, is placed immediately behind A B. The effect of this glass is to lessen the convergency of both the rays, but that of the violet most; and by this means they are made to converge to the same focus F.

By employing a third lens, the object-glass is rendered still more achromatic. The finest refracting telescopes that ever were made have triple object-glasses, consisting of two convex lenses of crown glass, with a concave lens of flint glass placed between them.

Before I proceed to the polarisation of light it will be proper to make you acquainted with the discoveries of Dr. Herschel and Dr. Wollaston, and to explain what is meant by double refraction.

By placing a very sensible thermometer in the different coloured portions of a prismatic spectrum, Dr. Herschel found that the violet rays indicated the least heat, and that the thermometer gradually rose as it was removed from one colour to the other, until it reached the red: here he naturally expected to find it at its greatest height, but to his great surprise this was not the case; for on removing it just without the red extremity of the spectrum, the thermometer rose still higher: plainly indicating the existence of an invisible ray beyond the red, hotter than the rest.—This ray has since been called the calorific or heating ray.

This discovery of Dr. Herschel's induced Dr. Wollaston to examine the other extremity of the spectrum; and the result of his experiments has been the discovering of another invisible ray, just beyond the violet, mani-

festing less heat than the rest, but possessing the peculiar property of changing muriate of silver from white to a black colour, and gum guaiacum from yellow to green.—This ray, from its effects, has been denominated the chemical ray.

These experiments, though extremely difficult to make, have been repeated and amply verified, and prove that the solar rays are separable into three principal parts; the calorific or heating rays, the colorific or colouring rays; and the chemical rays.

Another very remarkable discovery, said to have been made by the Marquis Ridolfi, and verified by the late Professor Playfair, is the extraordinary property possessed by the violet rays of magnetising a steel needle. Great doubts, however, have been entertained of the justness of these experiments, which seem, at least, to stand in need of further trial.

I now come to the subject of double refraction; by which is meant that curious property, possessed by certain crystals, of dividing a ray of light into two distinct sets of rays, so as to form two perfectly similar images of one and the same object seen through them.

This extraordinary phenomenon is most strikingly exhibited in Iceland spar, and sulphate of lime, the crystals of which are of a rhomboidal form.—See fig. 9 of misc. plate i.

If a piece of this spar be placed upon a sheet of white paper, on which small dots have been described, they will each appear like two distinct dots, more or less separated from each other, according to the greater or

lesser thickness of the piece of spar.—This plainly shews that the light, in coming through the spar, is separated into two complete rays. The refraction always takes place in the direction of the diagonal plane which joins the two obtuse angles of the crystal.—This plane is called the principal section of the crystal.

Let *a b c*, fig. 7, misc. plate i. represent the principal section of a crystal of carbonate of lime, *e* a ray of light falling on it at *f*. This ray will be divided into two complete rays, one refracted to *f g*, the other to *f h*—the former is called the ray of ordinary, the latter the ray of extraordinary refraction.

Experiment. Lay a piece of Iceland spar upon a sheet of writing paper, on which has been described two or three small dots with black ink. Each dot will appear like two, and if the piece of spar be turned round on the paper, the extraordinary image of each dot will appear to revolve round its ordinary image; the two images always lying in a line parallel to the diagonal joining the two obtuse angles, *a d*, fig. 7.

The double refraction of Iceland spar was known to Huyghens, who attempted to explain this extraordinary appearance by his hypothesis of the undulatory motion of light. The fact has always been considered as one well deserving the attention of philosophers; but it has lately acquired a still greater degree of interest by its connection with the important discovery of M. Malus, of the polarisation of light by reflection.

The polarisation of light is a subject far too extensive to be comprised in the narrow compass of a letter, I

will endeavour, however, to give you as distinct and comprehensive a view of the subject as I can, by describing one or two of the principal experiments.

Let *a b*, fig. 6, misc. plate ii. represent a ray of light coming from the candle *a*, and falling on the plate of unsilvered glass *b*, standing upright, and so placed as to receive the ray *a b* at an angle of incidence of 35° 25′; let this ray be again reflected to another unsilvered glass at *c*, also standing upright, and at the same angle of incidence, the reflection from this last plate will be in the direction c *d*, in the same plane as *a b* and *b c*.

Things being thus arranged, an eye placed at *d* will see the twice reflected image of the candle very distinctly; and the same will be the case, if instead of placing the second glass c, so as to reflect the image to *d*, it be placed so as to reflect it into the same plane, but in a contrary direction from *c* towards *f*.

Now, let *e* and *f* be a candle and glass placed in a similar situation with respect to each other as *a* and *b*; but instead of the second glass being in a vertical position, let it be inclined to the table as *g*, so as to receive the ray *f g* at an angle of 35° 25′. By the common principles of optics, the ray *f g* should be reflected to *h*; but an eye at *h* will see no image whatever of the candle at *e*, though the reflected image of the glass *f* itself will be distinctly perceived.

If the second glass be so inclined as to reflect the ray *b c* or *f g* neither into the same plane with the first incident and reflected ray, nor in a plane perpendicular to it,

but in one inclined to it, then a faint image of the candle will be seen, more or less bright as the reflection approaches nearest to the direction *c d* or *g h*.

This peculiar modification of light, which disposes it to be reflected into one plane, is called its polarisation. Thus, the ray *a b*, or *e f*, is said to be polarised in the plane *a b c d*, and depolarised in the plane *f g h*; and in planes inclined to these it is said to be partially depolarised.

The angle of 35° 25′, is called the angle of polarisation, because it is only under that precise incidence that the phenomenon completely takes place, at least with respect to glass.

For the angle of polarisation differs with the refracting power of the reflecting substance, and of the surrounding medium, and appears to be such that the incident ray, if refracted, would be perpendicular to the first reflection: thus the incident ray *a b*, if refracted, would proceed to *x*, and *b c* will be perpendicular to *b x*.

The refracted light *b x*, is polarised in a direction contrary to that of the reflected light *b c*: for if a glass be placed at *a*, parallel to *b*, it will not reflect light, but inclined, as at *g*, it will reflect in a plane at right angles to *a b x* and *b c*.

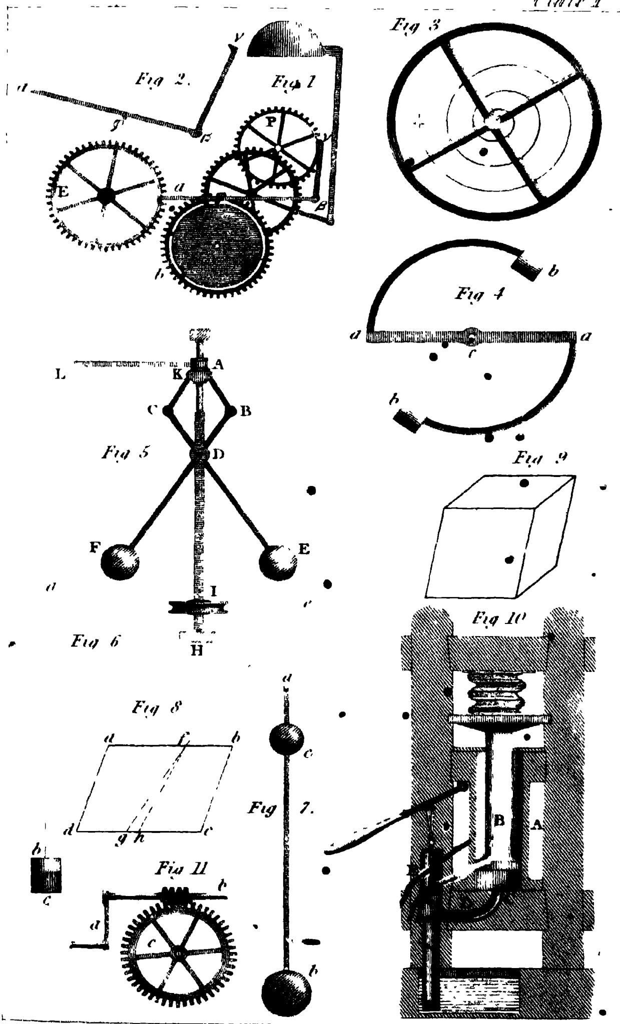
The ray ordinarily refracted by a doubly refracting crystal is polarised in the direction of its principal axis, the extraordinarily refracted ray in the transverse direction.

This, although a very rude and imperfect sketch, will

enable you to understand what is really meant by the polarisation of light. The subject is in itself an exceedingly difficult one, and has been rendered still more so by the vain attempt to reconcile it to idle preconceived theories, and elaborate calculations, founded on very uncertain data.

MISCELLANEOUS

Plate 1



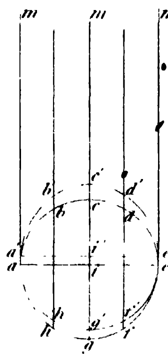
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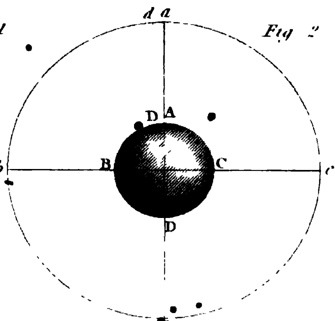
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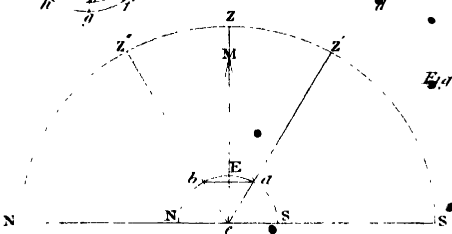
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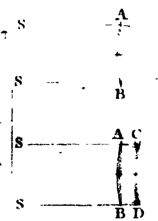
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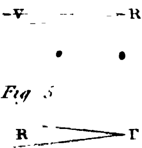
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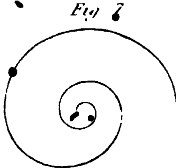


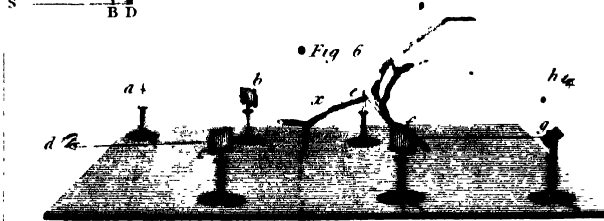












S.L.del. *W. Lowry, sculp*

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QUESTIONS

AND OTHER EXERCISES

On the several Letters contained in this Work; intended as well for the Examination of Pupils, as for a Guide to young Persons who would become their own Instructors in Experimental Philosophy and the Art of Composition. See Preface.

MECHANICS.

LETTER II. Page 5.

WHAT is meant by matter, and to what is the definition applicable?

What experiments prove that air is a body?

Is it known of what matter is composed?

Can you turn to fig. 1. and show how it is demonstrated that matter is infinitely divisible?

Mention some instances in which the division of matter is carried to very great lengths?

Are there not facts still more surprizing with regard to the natural divisions of matter?

Do the properties of extension and mobility, as applied to matter, require demonstration?

How is motion defined, and how many kinds of motion are there?

What does the principle of *inertia* imply, and how is it illustrated?

What circumstances tend to stop a body in motion? Give the example.

What inference is drawn from this?

How is the velocity of motion measured? Give the example.

How do you ascertain the velocity of a body?

How is the space run over found? Give the example.

Explain the course of a body in motion by fig. 2 and 3.

In what cases does a body in motion have the same direction, and in what cases a different direction.

Explain, by fig. 1, the composition of forces. Give the examples.

LETTER III. Page 15.

Why do the planets move in curve lines? Explain this by fig. 5.

What is meant by an accelerating motion? Give the example. Let it be illustrated by means of fig. 6.

By what laws is accelerated motion governed?

How many feet will a body fall in 4, 6, and 8 seconds; and how is the depth of a well &c. found by the motion of a falling body?

What is meant by attraction?

How many kinds of attraction are there?

Why do heavy bodies fall towards the earth?

What is meant by the attraction of cohesion, and in what cases does it take place? Give the examples of the bullets and cork.

What is capillary attraction, and what experiment illustrates it?

Explain the principle shewn by fig. 7, also that of the third experiment.

Mention some familiar instances of this kind of attraction.

What is meant by repulsion; and what examples illustrate the principle?

LETTER IV. Page 24.

What is the attraction of gravitation, and what motions depend on it?

What example proves that the power of gravity is the same in all bodies?

How did Sir Isaac Newton prove that gravitation is in proportion to the quantity of matter attracted?

What inference is drawn from this?

How are the apparent exceptions to this rule explained? Give the experiments.

By what are bodies kept steady on the surface of the earth?

How has the deluge been accounted for?

Is the earth a perfect globe?

Where is the power of gravity the greatest, and what laws does it follow?

What is the difference of weight of bodies at the surface and at particular heights above the surface of the earth?

What would a pound weight weigh at the distance of the moon, and how is this explained?

Does the earth gravitate towards other bodies, and how is it explained? Give the experiments

What is the cause of attraction, and what experiment did Dr. Maskelyne institute in proof of it?

Is gravity an universal principle?

LETTER V. Page 32.

What is the *first* law of motion, and how is it illustrated?

What is the *second* law of motion,

and how is it illustrated? Explain what is meant by figure 8.

What is the *third* law of motion, how is it illustrated, and what is learned from it?

On what does the collision of bodies depend?

How is the principle of elasticity explained?

What facts are mentioned in connection with elastic bodies?

Explain what is intended to be shewn by fig. 9 and 10.

What curious fact depends on the inertiæ of matter?

What is a pendulum? Explain the principle of pendulums in motion by fig. 11.

What is the point of suspension, and what is the rule with regard to the lengths of pendulums?

What is meant by the centre of percussion?

Where do pendulums vibrate the slowest, and what is the consequence of this?

LETTER VI. Page 42.

What is meant by the centre of gravity?

What is the line of direction?

On what principle do bodies stand, and on what do they fall? Explain what is meant by fig. 12 and 13.

What inferences are drawn from this?

How are the centres of gravity of different bodies found? Explain fig. 14.

In bodies revolving about one another, what does the centre of gravity describe?

Shew by fig. 15, how the centre of gravity is found?

In what case will scale-beams, &c. rest in any position?

Explain what is meant by figs. 16 and 17.

In what case is a waggon, &c. liable to be overset, and under what circumstance is there no danger? See fig. 18.

Explain what is meant by fig. 20.

How are the motions of a loaded cylinder and a double cone explained? See fig. 21 and 22.

Mention some familiar instances in which the equilibrium of motion is explained upon the principle of gravity.

Explain the principle of the rolling candlestick, fig. 23.

What circumstance will the knowledge of the centre of gravity enable us to explain?

LETTER VII. Page 49.

For what are the mechanical powers used?

What is meant by the word *momentum*?

Explain the experiment shewn by fig. 24.

Why do cannon-balls do more mischief than the ancient battering rams?

What are the mechanical powers, what do they enable a man to perform, and what is derived from them?

Explain the principle of the lever by fig. 25.

With fig. 26 point out what is intended by the first experiment.

In what cases is there an equilibrium between the weight and the power?

How is the velocity of a body measured? Explain this by fig. 27.

Point out what is meant by the phrase "What we gain in power we lose in time."

Explain the principle of the steel-yard, fig. 28.

What instruments, &c. are to be referred to levers of the first kind?

Explain the principle of a lever of the second kind, fig. 29.

What instruments are to be referred to this?

Explain the principle of a lever of the third kind, fig. 30.

What familiar instances have we of levers of this sort? Explain what is meant by fig. 31.

What is meant by th. fourth sort of lever, fig. 32?

LETTER VIII. Page 58.

Explain the principle of the wheel and axis, fig. 33, 34, 35.

To what is the wheel and axis applied?

Explain the principle of the wheel and pinion.

To what is the wheel and pinion applied?

Explain the principle of the crane represented by fig. 36.

How does the circular crane act, fig. 37?

What is the principle of the windlass, fig. 38?

Explain the principle of the pulleys, figs. 39—44.

How is the advantage gained by pullies estimated?

What inconveniencies attach to the working of pullies?

In what respect are these defects obviated by Mr. White's pullies?

LETTER IX. Page 65.

Explain, by fig. 45, the principle of the inclined plane.

For what is the inclined plane chiefly used?

How is the force of a body descending down an inclined plane estimated?

Point out what is intended by fig. 46, 47, and 48.

How is the advantage gained by the inclined plane estimated?

What instruments are referred to the inclined plane?

Explain the principle of the wedge, fig. 49.

For what is the wedge used, and how is the advantage gained by it estimated?

Of what are wedges usually made, and how are they generally used?

What instruments are referred to the wedge?

Explain the principle of the screw, fig. 50.

What are figures 51 and 52 intended to explain?

How is the power gained by the screw estimated?

LETTER X. Page 71.

To what are the principles of the mechanical powers reducible?

In the mechanical powers how are the powers and weights arranged?

How much is to be allowed in practice for friction?

What is friction, how is it represented, and how does it vary?

Under what circumstances is the impediment from friction the smallest?

For what are friction rollers used? Explain what is meant by figs. 53, 54, and 55.

Point out the action of the machine represented by fig. 56.

Give the example to prove that "what is gained in power is lost in time."

What proportion of labour is that of a man to a horse?

Why is running water preferable to wind as a moving power?

Which is the most powerful of agents, and to what is it applied?

To what motions are heavy weights applied?

In what respect is the force of a spring useful as a moving power, and in what does it differ from that of a descending weight?

LETTER XI. Page 77.

With what are bodies in motion compared, and how is the subject illustrated?

To what investigation have the properties of the lever been applied?

Explain this by fig. 57.

What inference was deduced by Galileo? Explain this by the figure.

What reason is assigned for the stalks of corn, the quills of feathers, &c. being hollow?

To what has this principle been applied?

What bodies, as to large and small, are more in danger of accidents?

How is the force which tends to break bodies estimated? Explain this by fig. 58.

What circumstances must be considered in the construction of mechanics?

In what way is a compound machine to be examined? fig. 56.

How is the mechanical power of an engine discovered?

Illustrate this with the example, fig. 56.

How is the power gained by

wheel-work calculated? Give the examples.

What rules are deduced from this? Give the example.

LETTER XII. Page 87.

Explain, by fig. 59, the parts of the inside of a clock.

What effect is produced by the motion of a pendulum?

What regulates the velocity of the wheel-work, and how is this explained?

Point out the method by which the hour and minute hands are moved.

Explain by what means time is so exactly measured by a pendulum.

Is the weight a necessary part of a clock.

Explain the striking train of a clock.

Explain what is meant by fig. 62*.

Of what are watches composed?

Explain, by means of the figures, in what way they are constructed.

How does the watch act after it is wound up?

Why does the hour-hand turn 12 times slower than the minute-hand?

Why is the fusee cut into a spiral form?

How is the motion of a watch adjusted?

Repeat the lines from Lucretius on time.

How is time noticed, and how is it measured?

What instruments have been used to measure time?

Explain the principles of the hour glass, clepsydra, and sun-dial.

What is the most equable motion in nature, and what was the cause of the divisions of time?

Why are time-pieces faster in some countries than others?

HYDROSTATICS.

LETTER XIII. Page 102.

Of what does the science of Hydrostatics teach?

To what does it particularly relate?

How is the science of hydrostatics distinguished from that of hydraulics?

What is meant by a fluid, and how many kinds of fluids are there?

What is said of their particles, and for what circumstances does this theory account?

How are fluids distinguished from liquids?

What particularities attach to water which do not belong to solids?

Why was it supposed formerly that fluids had no weight in fluids of the same kind?

What is the experiment that refutes this opinion?

Why is a bucket so easily drawn up a well?

Give an account of the experiments to prove that fluids press in all directions. See Plate *Hydrostatics*, fig. 1—4.

What pressure does the bottom of a vessel, filled with any kind of fluid, sustain?

How is the upward pressure distinguished from that downwards?

Can lead be made to swim, fig. 5?

What is the hydrostatical paradox, fig. 6. and 7?

What inference is drawn from this?

In what respects does pressure differ from gravity?

Explain the nature and principle of the hydrostatical paradox, fig. 8.

What will be the consequence of increasing the length of the tube?

Explain the mechanism of Bramah's hydrostatic press.

LETTER XIV. Page 113.

What bodies swim, and what sink in fluids?

What is meant by the specific gravities of bodies, and what is necessary to ascertain them?

Who made this discovery, and how was it found out?

If a body be suspended in water, what weight does it lose?

In what case do bodies lose equal and in what unequal weights?

Explain the nature of the hydrostatical balance, fig. 9.

Give an account of the first experiment.

How is the specific gravity of a guinea found, and what is the general rule?

Point out the method of finding the specific gravity of a piece of flint glass.

How is the specific gravity of wood, that is lighter than water, found?

How is the specific gravity of mercury found?

What is the construction of the hydrometer, fig. 10, and how is the specific gravity of fluids found by it?

How are the specific gravities of fluids estimated?

What experiments are explained by the knowledge of the specific gravities of bodies? fig. 11. and 12.

Can fluids of different specific gravities be arranged upon one another?

Explain the principle of the table, page 120.

How is the ascent of air balloons accounted for?

Can you give some account of Lunardi's and Garnerin's exhibitions? fig. 10 and 11. Plate II. *Hydrostatics.*

On what does the diving bell depend for action?

Explain the diving bell, represented by fig. 13, and for what is it used?

LETTER XV. Page 124.

What is learnt from the science of hydraulics?

Repeat the rule for finding the velocity of spouting water, and from what does this rule result?

How does pressure against the sides of a vessel increase, and how is it illustrated by experiment?

By what method is it proved that the pressure of fluids follows the same law as falling bodies? fig. 1, Plate II. *Hydrostatics.*

What is the pressure on the bottom and sides of a cubical vessel equal to?

Give some account of the pressure of fluids as it relates to their motion through pipes.

What difference exists between pressure of fluids against the side of a vessel, and the velocity of those fluids ...

By what law does the velocity of spouting water decrease, and what instrument depends on this principle?

How is the clepsydra constructed?

Why is great strength necessary in the banks of rivers, canals, &c.?

Point out what fig. 2. is to explain.

What is the general rule with regard to the horizontal distance to which a fluid will spout?

What do the pipes pointing obliquely shew? fig. 2.

Can fluids be conveyed over hills, and through valleys, and why?

Describe the principle and experiments relating to the syphon, fig. 1, 3, 4, and 5.

Why does not water spouting from a pipe, fig. 2, rise to the level of that within the vessel?

Explain the principle and structure of the common pump, fig. 7.

Explain the operation of a forcing pump, fig. 8.

Point out what fig. 9 is intended to shew.

PNEUMATICS.

LETTER XVI. Page 134.

What is the air, and to what height does it extend?

What properties does it possess in common with other fluids, and in what particulars does it differ from them?

To what is the science of Pneumatics devoted?

By what experiments is it proved that air is a substance?

What is the average weight of air? Work the example in note, page 136.

Explain the structure of an air-pump, fig. 1. Plate *Pneumatics*.

By what law is the pressure of fluids regulated?

Explain the 5th, 6th, and 7th experiments. See fig. 2.

Point out the air's elastic power by experiment 8, and fig. 3.

Do none of these experiments depend on suction? and how is this shewn by fig. 4.

How is a piece of wet leather made to lift a heavy weight?

Explain the operation of the hemispheres. fig. 5.

How does the transferrer act, fig. 6.

What facts are shewn as resulting from the pressure of the atmosphere?

How does the fountain in vacuo act? fig. 7.

Explain the principle of fig. 8, and how are the changes of the atmosphere ascertained?

What experiments prove the elasticity of the air? experiments 16, 17, and 18.

Can air be compressed into a less space than it usually occupies, and how is it proved by fig. 9?

What is the elastic spring of the air always equal to, and how is it proved?

What facts are there to shew that the air near the earth is denser than that higher above it; and how far is the atmosphere supposed to extend?

Explain the operation of the artificial fountain, fig. 10.

LETTER XVII. Page 146.

Explain what fig. 11 is intended to shew.

How is it shewn that light bodies are more affected than heavy ones by the resistance of the air, fig. 12?

How is mercury forced into the pores of wood?

What do experiments 4, 5, and 6, prove?

Why does the smoke of a candle just extinguished ascend?

What experiment shews that air is necessary to sound?

In what air is sound the strongest?

Is air necessary to sound and animal life?

Explain the 12th experiment.

Can air be perfectly exhausted by means of the air-pump?

Point out the action and theory of the Torricellian experiment, fig. 13.

Explain the structure of the barometer, fig. 14.

How high can the mercury be made to rise, and why?

What is the variation of the scale, and what is the construction of the Vernier?

To what is the variation of the mercury in the barometer applied?

What does the rising and falling of the mercury presage?

When is bad weather not expected to last?

When may a continuance of fair weather be expected?

What does the unsettled state of the mercury denote?

Explain the principle of the hygrometer, and for what is it used.

Point out the nature of a rain-gauge, and for what it is used.

Explain the structure of the thermometer, fig. 16, plate II.

How is it graduated, and what is the utmost extent of this instrument?

Explain the nature of the thermometer invented by Mr. Wedgewood.

Do you understand the principle on which the "scale of heat" is constructed? page 157.

Show how the centigrade scale is reduced to that of Fahrenheit, and *vice versa*.

LETTER XVIII. Page 159.

How are great heights measured by the barometer?

What is the pressure upon the human body?

Can you explain the structure and operation of the steam-engine, figs. 17 and 18?

What work will a steam-engine perform, and at what expense?

To what were steam-engines first applied, and for what purposes are they now used?

ACOUSTICS.

LETTER XIX. Page 167.

In what does the science of acoustics instruct us?

What opinions had the ancients respecting sound?

Will all fluids convey sound?

With what velocity does sound travel, and how is that ascertained?

Do all kinds of sound travel at the same rate?

From what kind of bodies do *clear*, and from what kind do *harsh* sounds proceed?

Is every substance a conductor of sound?

In what way may a trifling scratch with a pin be heard at some distance?

How is experiment IV. conducted, and what is the result?

Is the earth a conductor of sound?

Of what is sound the effect?

Under what circumstances is sound reflected?

What is an echo? Explain the experiment, fig. 19.

What is the theory of pronunciation so as to obtain a distinct echo?

Explain the principle of the whispering gallery at St. Paul's.

What is the principle of the speaking trumpet, and of speaking figures?

Shew what is meant by figs. 20 and 21.

What are the causes of the variety of sounds

What does fig. 22 shew?

How are the sounds of an Eolian harp produced?

What is wind, and how is it produced?

Explain experiment 9.

On what does the smoke-jack depend for action?

How are the winds denominated?

How many kinds of wind are there, and what are they?

OPTICS.

LETTER XX. Page 178.

On what does the science of Optics depend, and what is said of the particles of light?

At what rate does light travel, and how was it observed? Explain this by fig. 1, Plate I. *Optics*.

What have philosophers conjectured on this subject?

What experiment proves that light moves in all directions without any impediment?

At what distance can a candle be seen in a dark night?

By what law does the intensity of light increase? Give the illustration.

What is meant by a ray of light?

What is refraction, as applied to light? Explain fig. 2.

When is light drawn nearer to a perpendicular, and when does it proceed farther *from* a perpendicular?

How are objects seen?

Explain experiment 4.

What is the axiom in Optics?

Why does a straight stick, immersed in water, appear crooked?

Does water appear deeper or shallower than it really is?

Are the heavenly bodies seen where they really are? fig. 3.

Explain experiment 6.

LETTER XXI. Page 185.

With fig. 4 explain the structure of the several kinds of lenses.

What effect is produced by lenses?

When are rays said to converge, fig. 5?

How is the focus of a lens found in a plano-convex lens, and what is the reason of it?

What is the distance of the focus of a double convex lens? see fig. 6.

What is a common burning-glass?

Do you recollect the experiments which were made with Mr. Parker's large burning-glass?

Can you explain the principles illustrated by figs. 6, 7, and 8?

How is the experiment made?

What is the rule for finding the image or picture of an object?

Tell me what fig. 9 is intended to explain.

How is fig. 10 explained, and what is meant by an imaginary focus?

Where are the foci of the different kind of lenses to be found?

Explain what is meant by reflected light, see fig. 2.

What general maxim recurs in this part of the subject?

Explain what fig. 11 is intended to illustrate.

Can a person see the image of his whole person in a glass half as tall as he is high?

Under what circumstances, and why, are two images of the same candle seen in a looking-glass?

Is the image as vivid as the object?

Explain the effect of fig. 12.

When is the image of an object inverted, and when erect, and when will the image and object coincide? see figs. 13, 14, and 15.

What are anamorphoses, and how are they produced?

LETTER XXII. Page 195.

Of what is light composed, what are the several colours excited by it, and which is most, and which the least refrangible?

How many colours are there, and how are whiteness and blackness produced?

Illustrate, by fig. 16, the principle of colours.

What is inferred from the oblong figure of the image of a ray of light?

What analogy is there between colour and sound?

How is white produced by mixing other colours?

How is the rainbow produced?

Explain the principle of the rainbow, figs. 17 and 18.

Explain the structure of the eye, figs. 19 and 20.

What are the three humours called, and what are their uses?

How are objects seen? fig. 21.

Can you mention what Dr. Young says on this subject?

What are the causes of indistinct vision?

LETTER XXIII. Page 203.

How are the colours of bodies explained, and what are white and black?

How is it proved, that colour is not inherent in bodies?

Which have been supposed to be the largest, and which the smallest particles of light, and why?

How is it proved, that light is the cause of colour?

How are the colours of natural bodies produced?

What bodies reflect the greatest quantity of light?

What reason is there to suppose that all bodies are naturally transparent?

How are opake bodies renderod transparent and the reverse?

On what principle is the variety of colours in some stuffs, silks, &c. explained?

What theory is adopted by Mr. Delaval?

Explain the principle of the microscope? see figs. 22, 23, and 24.

Does a lens actually magnify objects? Explain this by experiment IV.

How many kinds of microscopes are there, and what is a single microscope?

Explain the structure of a compound microscope, figs. 25 and 26.

Explain the nature and use of the solar microscope, fig. 27.

What are telescopes?

Explain, by figs. 28 and 29, the structure of the refracting telescope.

Point out the principle of the reflecting telescope.

Can you give any account of the "Camera Obscura," and "Magic Lanthorn?"

What is the principle of the phantasmagoria?

What are multiplying glasses?

ASTRONOMY.

LETTER XXIV. Page 216.

What great discoveries have been lately made in astronomy?

Why do the apparent motions of the heavenly bodies excite no surprise?

Why are the stars not seen in the day?

Can the distances of the heavenly bodies be ascertained?

Why are some stars called *fixed* and some denominated *planets*, and how is the difference between them observed?

What are comets?

Can the periods of the planets and comets be ascertained?

Do planets and comets differ from the fixed stars by their light, and how are they distinguished?

How are the fixed stars divided and distinguished from one another?

How did the ancients divide the starry sphere, and how is this done by the moderns?

Into what are the heavens divided?

What does the zodiac include?

Have any of the single stars particular names? point them out on the celestial globe.

What is meant by a nebula, and what is Dr. Herschel's account on this subject?

Are the fixed stars supposed to be absolutely immoveable with respect to one another?

LETTER XXV. Page 227.

What is said of the sun?

Of what does the solar system consist?

What is the common opinion respecting the world, and what did Pythagoras teach?

What theory did Ptolemy adopt?

What was Tycho's system, and what improvement was made upon it?

Who revived the Pythagorean system of the world, and why is it now denominated the Newtonian system?

Explain what is intended by plate I. of *Astronomy*.

Which are the "inferior" and which the "superior" planets, and why so called?

What motions have the secondary planets and comets?

Explain what is meant by fig. 1, plate II. *Astronomy*,

When are planets said to be in "conjunction," and when in "opposition?"

What are the "centrifugal" and "centripetal" forces? Explain this by fig. 1.

What is the general rule for ascertaining the distances and velocities of the planets? Explain the table, page 235.

LETTER XXVI. Page 236.

What motions has the sun, and how are they ascertained?

Can you give any account of Dr. Herschel's speculations with respect to the moon and sun?

How many planetary bodies attend the sun, and what are their proportional distances?

In what are the motions comprehended?

Give me some account of Mercury, and explain its motions by fig. 2.

Why are Mercury and Venus never seen in that side of the heavens which is opposite to the sun?

To what has the motion of Mercury been compared, and why? fig. 2.

Why do the apparent diameters of the planets vary; and when does Mercury appear largest and least? fig. 2.

What is meant by a transit; and what do transits prove?

Do Mercury and Venus exhibit similar phases to those of the moon?

What account is given of Venus? What proportions of light and heat do Mercury and Venus enjoy?

LETTER XXVII. Page 244.

Give me some account of the earth and its motions.

What does the inclination of the earth's axis produce?

What is said of the motions of the earth and moon combined?

What length is the diameter of the moon, and at what distance is that body from the earth?

How long is the moon turning on its axis, and what is the effect of this?

What reasons are there to induce one to believe that the earth is a round body? see fig. 3.

What is the true level of the earth? Is the earth a perfect globe?

Does the earth turn on its axis, and what effect is produced by this motion?

Explain what is meant by fig. 4, with regard to the illumination of the earth?

How is it known that the earth has an annual motion round the sun?

Point out the cause of the seasons, and shew the reasons for long and short days.

Why are the winters colder than the summers?

LETTER XXVIII. Page 253.

What is said of the moon, and what is the difference between a periodical and synodical month?

Explain what fig. 5 is intended to represent.

Does the earth serve to enlighten the moon, and what effect does it produce?

What is an eclipse of the moon? Explain this by figs. 6 and 7.

On what does the duration of an eclipse depend?

What is meant by the term digits?

Where are lunar eclipses visible, and on what does the length of eclipses depend?

On what does the faint light of the moon in an eclipse depend?

In what length of time do the moon's nodes come into the same position as they are at any given period, and what effect does this produce?

Explain the nature of an eclipse of the sun, fig. 8.

What observations does Dr. Vince make on the subject of eclipses?

To what have eclipses of the moon been applied?

How many eclipses are there in a year, and when do they usually happen?

Give some account of the tides.

When are tides the highest and when the lowest?

LETTER XXIX. Page 264.

Give some account of Mars and his motions, see fig. 9.

When does he appear full-faced to an inhabitant of the Earth, and when otherwise?

Is there any analogy between Mars and the Earth?

What smaller revolving bodies are found between the orbits of Mars and Jupiter?

What account is given of Jupiter and his moons?

What is discovered from the eclipses of Jupiter's satellites? Give the example.

Give some account of Saturn, his satellites, and rings.

What is said of the Herschel planet?

What account is given of comets?

What reasons are there for believing that comets are very solid bodies?

Can you explain, by fig. 10, in what way the distance of the moon from the earth is ascertained?

Explain what is meant by Parallax, and how the distances of the sun, moon, and planets are found.

Explain the methods of finding the latitude and longitude at sea.

ELECTRICITY.

LETTER XXX. Page 278.

What is said of the electric fluid?

What are the effects produced by the electric fluid, and how is it made perceptible to the senses?

Explain the structure of the electrical machine, fig. 1, and give

some account of the first four experiments.

Give some account of the difference between conductors and electrics.

What is the meaning of the word "insulated?"

What is the difference between *positive* and negative electricity?

What are the theories of Dr. Franklin and Du Fay? Give an illustration of Dr. Franklin's theory.

What is meant by an electrical shock?

Explain the nature of the electrical Leyden phial, fig. 2.

What is meant by an electrical battery?

Give some account of the 6th, 7th, and 8th experiments.

Explain the action of the electrical bells.

Give an account of the 10th, 11th, 12th, 13th, and 14th experiments.

Are lightning and electricity effects of the same cause?

To what practical purposes has the science of electricity been applied?

GALVANISM.

LETTER XXXI. Page 288.

What fishes possess the electrical properties?

How were the discoveries of Galvani made?

How is the limb of a dead animal put in motion?

Give an account of the first three experiments.

In what way are the taste and sight affected by galvanism? Experiments 4 and 5.

How are the conductors of this fluid divided; and which are the perfect, and which the imperfect conductors?

Of what does a simple combination consist?

Explain the structure of the pile represented by fig. 6.

How does the battery, fig. 7, act?

Explain the method of operating with the battery represented by figs. 8 and 9.

How is water decomposed, (see figs. 9 and 10,) and of what is it composed?

What conclusions are drawn from this subject?

MAGNETISM.

LETTER XXXII. Page 295.

What is magnetism, and from what does it derive its name?

To what has the magnet been applied?

How is the attractive power of the magnet shewn, and to what can it be communicated?

How will a magnet at liberty arrange itself, and how are the poles of a magnet found?

In what circumstances do the poles of a magnet attract and repel each other?

What is meant by the "variation" of the needle, and what is meant by its "dipping?"

What is the magnetic meridian, and what is the declination of the magnet?

In what parts of a magnet is the attraction the strongest?

Explain how the polarity of the magnet is useful to mariners.

What is meant by the mariner's compass?

Is the variation of the compass the same in different parts of the earth?

What is meant by the "dipping needle?"

How is magnetism communicated to iron, &c.?

What is meant by a horse-shoe magnet, and what does *arming* a magnet mean?

Give some account of the discoveries of Professor Oersted.

Explain the structure of the mariner's compass.

MISCELLANEOUS.

LETTER XXXIII. Page 303.

Describe the method employed by Captain Kater for determining the length of a pendulum.

In what respects does the Achromatic telescope differ from the simple one?

Explain what is meant by calorific and chemical rays.

What is the discovery said to have been made by the Marquis Ridolfi?

Explain what is meant by double refraction.

Give some account of the discoveries of Mr. Malus, and explain what is meant by the polarisation of light.

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